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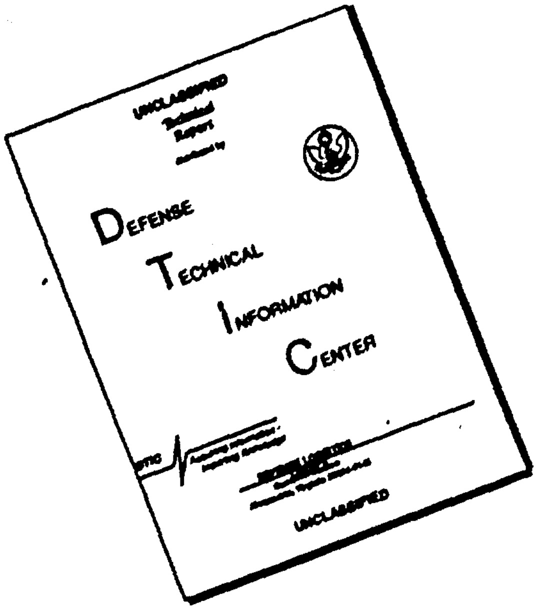

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Project NY 420 010.5
Technical Memorandum M-097

TEST OF ANCHORS FOR MOORINGS AND GROUND TACKLE DESIGN IN MUD BOTTOM

15 December 1954

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R.C. Towne and J.V. Stalcup

SUMMARY

The U.S. Naval Civil Engineering Research and Evaluation Laboratory conducted tests in a mud bottom to determine the holding power of the BuDocks-designed steel, concrete-mushroom, and concrete wedge-shaped anchors, and to compare the behavior and holding power of these anchors with those of the present type of stockless anchors, with and without stabilizers.

Tests were conducted on Navy stockless anchors, with and without stabilizers. Holding-power-to-anchor-weight ratios in mud bottom averaged 3.31 to 1 with stabilizers and 2.66 to 1 without stabilizers. It was concluded that stabilizers should be installed on Navy stockless anchors utilized in moorings in mud bottoms.

Additional tests were made on BuDocks-designed anchors. Of these the 7500-lb concrete-steel anchor had the largest holding-power-to-anchor-weight ratio, 2.92 to 1.

Tests were also made on two new design Baldt mud anchors and on a Croseck anchor. The holding-power ratio, 6.62 to 1, of the 3170-lb anchor was greater than that of the Navy stockless anchors manufactured by the Baldt Anchor Division.

Comparative holding-power tests were conducted on Lightweight anchors and Danforth anchors. Average holding-power ratios were 3.18 to 1 and 5.87 to 1, respectively.

Two anchors using proposed new design criteria were designed and fabricated at the Laboratory. These provided an average holding-power-to-weight ratio of 10.1 to 1 and 10.0 to 1, respectively. Maximum holding power in mud of the anchor fluke angle was determined to be 50 degrees. It is recommended that a group or 'family' of mooring anchors be developed utilizing the design criteria obtained from the results of the sand and mud bottom tests.

PREFACE

These tests are a continuation of the anchor tests conducted in sand[1] during the period from 1948-1953. The sand tests produced an effective means of stabilizing stockless anchors, established the fluke angle for obtaining a maximum holding power in sand, concurred with the validity of the L^3 law for holding power of an anchor, and provided a basis for the design criteria of an improved mooring anchor.

These tests were made in order to establish the holding power and proper fluke angle of the present anchors in mud bottom and to verify the proposed anchor design criteria. The Cooperation and assistance furnished by the San Francisco Naval Shipyard, Hunters Point, made it possible to complete these tests with a minimum of delay and cost.

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INTRODUCTION

The Bureau of Yards and Docks initiated these tests as a means of developing a stable mooring anchor for utilization in vessel moorings and ground tackle for floating structures such as drydocks, cranes and barges. The Bureau is responsible for the design and construction of mooring facilities to protect these vessels from the combined forces of waves, currents, and winds. Tests were to be conducted in sand, mud, and clay bottoms in order to provide sufficient knowledge of anchor reaction in these types of soil to factually determine their holding power and to permit development of anchor-design criteria.

These anchor tests, conducted by the U.S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California, under Project NY 420 010.5 were made in the mud bottom of San Francisco Bay at the San Francisco Naval Shipyard, Hunters Point, California.

ANCHOR TEST APPARATUS

The test apparatus for mud bottom tests consisted of two 5 by 12 pontoon barges, used to carry the test equipment, and a 5 by 14 pontoon warping tug, used to drop and retrieve the anchors. The test equipment was composed of a 400,000-lb capacity electric dynamometer to measure the holding power of the anchors and a model BU-140 Skagit winch with a six-part line for dragging the ancho The winch was spooled with 2500 ft of 1 3/8-in.-diameter wire rope, and the wire rope was reeved through sheaves mounted on the two barges to form the six-part line. One of the 5 by 12 pontoon barges was anchored with two 30,000-lb Navy stockless anchors and the other barge was attached to the test anchor with suitable lengths of anchor chain. Figure 1 shows a general view of the barges at Hunters Point during the tests. In this view the test anchor is located beneath the buoy between the two farthest barges and the buoy in the right foreground locates one of the 30,000-lb stockless anchors used to hold the barges in position.

SOIL SAMPLES

Samples of the mud were taken in the path of the anchor test pulls down to a depth of 27 ft utilizing a 2-in.-diameter Porter sampling device. A laboratory analysis of the soil was conducted by the Twelfth Naval District Public Works Office, San Bruno, California. Tests performed on the samples included a mechanical analysis (see Figures 2 and 3), liquid and plastic limits, specific gravity unconfined compression tests, and consolidation data (see Table I and Figures 4 to 9). Unconfined compression tests were performed on the samples at their natural water content. The rate of strain was maintained between 1/2 per cent to 1 1/2 per cent per minute. The type of failure is shown in Figure 10. For the consolidation tests, the specimens taken in the field were placed in a fixed-ring consolidation device, seated firmly, and loaded in increments as shown. Direct shear tests were made on the undisturbed specimens, as taken with the Porter sampler, in a consolidation-quick condition, at a constant displacement of .05-in. per minute (see Figures 11, 12, and 13). Shear tests were made on samples taken at a depth of 22 ft only, because of the fluid nature of the material above this depth. Triaxial shear data were obtained by conducting unconsolidated-undrained tests on the samples as taken with the Porter sampler (see Figure 14). The test lateral pressure was applied instantaneously and the specimen sheared quickly, using a stressometer of the proving-ring type to register the shearing load. Volume changes were noted during the tests. Rate of strain was equal to about 1 per cent per minute (see Figure 15).

The soil contained approximately 60-per cent clay particles with 62-per cent water content, and the shear resistance was .41 ton per sq ft.

ANCHOR CHAIN TESTS

Test pulls of the anchor chain alone were conducted to determine the resistance of the chain dragging through the mud bottom. The average holding power after 50-ft drag of 450 ft, 360 ft, and 270 ft of 2 3/4-in. anchor chain was 13.9, 11.1, and 7.6 kips, respectively, and for 180 ft of 1 1/2-in. anchor chain, 1.9 kips.

The proper anchor chain lengths for a 0-, 6-, or 12-deg chain angle at the anchor were obtained by the formula presented in NAVDOCKS Mooring Guide.[2]

ANCHOR AND TEST INFORMATION

The holding powers of the anchors were recorded at 5-ft intervals for a distance of 180 ft, thus providing data for plotting a continuous curve of anchor holding power. The ratio of the holding power to anchor weight in air, HP/wt, as used in this report, is taken after the anchor has dragged a distance of 50 ft. Longer distances of drag will produce a larger holding power; however, a distance of 50 ft has been selected as the maximum allowable travel for moorings in confined locations.

The vertical force required to break the test anchors loose from the mud bottom at the end of each test pull was measured by means of a strain gage mounted on the warping-tug winch line (see Figure 16). The depth of water was approximately 30 ft at the test site.

NAVY STOCKLESS ANCHORS. The present Navy stockless anchor is designed for shipboard operation and has been adopted for mooring use without modification. The 1500-, 3000-, 6000-, 10,000-, 20,000-, and 30,000-lb all steel anchors used for test were pulled initially without stabilizers at a 0-deg chain angle only. Figure 17 shows a typical Navy stockless anchor. Subsequently each individual anchor was equipped with a suitable stabilizer (see Table 2) and was retested at 0-, 6-, and 12-deg chain angles. The steel-plate stabilizers were designed by the Bureau of Yards and Docks and had been tested previously in sand bottom.[1] Six test pulls were made on each anchor at each chain angle. Figure 18 shows a typical stabilized anchor, and Figures 19 and 20 are graphs of the test pulls on the 10,000-lb anchor, with and without stabilizers.

Table 3 contains the holding power of each anchor with and without stabilizers, the fluke angle, the average holding powers, minimum holding power which occurred during the six test pulls, the holding-power-to-anchor-weight ratio, depth of burial into the mud, and the average vertical force required to break the anchors loose from the mud bottom. The largest average HP/wt ratio at 50 ft was 5.60 to 1 for the 1500-lb anchor. The average HP/wt ratio at 50 ft for all the anchors was 3.31 to 1. It was observed during the initial tests on the stockless anchors that the holding powers were not uniform which indicated that the flukes were not opening properly. A study was made to determine this effect upon the holding powers of the anchors.

NAVY STOCKLESS ANCHORS - FIXED FLUKE. Three of the Navy stockless anchors were selected for these tests in order to study the effect of the fluke angle upon the uniformity and amount of the holding power. The 'fluke angle,' as used in this report, is the angle subtended between the shank and the flukes, when the flukes are rotated to extreme open position.

The anchors used were the 5000-, 10,000-, and 20,000-lb Navy anchors with stabilizers. The flukes were fixed at open position and the anchors were each pulled six times at 0-deg chain angle. The holding power ratios found during the previous tests were increased from 2.85 to 1, 2.42 to 1, and 2.21 to 1, up to 3.53 to 1, 4.86 to 1 and 4.32 to 1, respectively. In addition, the holding powers were more uniform (see Table 4). Figures 21 to 26 are graphs of the test pulls on the anchors with and without fixed flukes.

BUDOCKS DESIGN ANCHORS. Three steel anchors, a 7500-lb concrete-steel, a 1430-lb straight-plate, and a 1430-lb curved-plate, were fabricated at the Laboratory for test (see Figures 27, 28, and 29). The 7500-lb concrete-steel anchor was tested at 0-, 6-, and 12-deg chain angles while the remaining two anchors were pulled at a 0-deg chain angle only. Results of these tests are shown in Table 5. The average HP/wt ratio was 2.92 to 1 for the 7500-lb concrete-steel anchor and 2.23 to 1, 2.44 to 1, for the straight-plate and curved-plate anchors, respectively. Figures 30, 31, and 32 are graphs of the test pulls for the three anchors.

BALDT DESIGN ANCHORS. The Anchor, Chain and Forge Division of the Boston Metals Company, Chester, Pennsylvania, furnished three anchors for test, a 3170-lb Baldt, a 3650-lb Baldt and a 3060-lb Croseck (see Figures 33, 34, and 35). These anchors were pulled at 0-deg chain angles only. Initial tests on the 3170-lb Baldt anchor indicated that the flukes were not opening in every test; therefore, the chain length was shortened to provide an initial lift on the anchor shank, in effect opening the flukes. The effect of this procedure was to increase the HP/wt ratio from 2.66 to 1 to 6.62 to 1. Results of the tests are contained in Table 5.

LIGHTWEIGHT ANCHORS. A 500-lb and a 1000-lb Lightweight anchor were tested at 0-, 6-, and 12-deg chain angles for comparative purposes (see Figure 36). In addition, tests[3] were made on 2000-, 3000-, 4000-, and 10,000-lb anchors for the Bureau of Ships. The results are included in Table 5. The largest HP/wt ratio was 3.90 to

1 for the 3000-lb anchor and the average HP/wt ratio was 3.18 to 1 for all the Lightweight anchors. Figure 37 is a graph of the test pulls on the 10,000-lb anchor.

DANFORTH ANCHORS. The Danforth anchors are commercial anchors patented by Mr. R.S. Danforth of Berkeley, California, and were loaned to the Laboratory for comparative test purposes. The anchors tested weighed 2510, 2770, 4000, 10,000, and 12,000 lb. The flukes of the anchors used in these tests were fabricated from steel plate rather than cast or forged, with the exception of the 4000- and 10,000-lb anchors (see Figures 38, 39, 40, and 41).

The anchors were pulled at 0-, 6-, and 12 deg chain angles with the exception of the 165-lb anchor which was pulled at 0-deg chain angle only. Test results are contained in Table 6. The largest HP/wt ratio was 9.92 to 1 for the 2770-lb anchor and the average HP/wt ratio for all the Danforth anchors was 5.87 to 1. Figure 42 is a graph of the test pulls on the 10,000-lb anchor.

FLUKE-ANGLE TESTS. These tests were conducted in order to establish the fluke angle which would provide the maximum holding power for any anchor in mud bottom. The 2770-lb Danforth anchor was utilized in these tests because its construction permitted the fluke angle to be readily varied to large angles as it was anticipated that a larger fluke angle would be established for mud bottom than was found for sand bottom.

The anchor was tested at a 0-deg chain angle with fluke angles of 45, 50, 55, 60, 70, and 80 deg. Figure 43 is a graph of the test results. The maximum holding power was found to occur at a fluke angle of 50 deg. The HP/wt ratio at this fluke angle was 20.5 to 1. This ratio is excessive for mud bottoms as explained in the Discussion Section.

PROPOSED MOORING ANCHOR DESIGN. The Laboratory fabricated two anchors, designed on the basis of the test results of the mud and sand bottom tests. The first anchor, weighing 1620 lb was fabricated from steel plate, with movable flukes opening to a 60-deg fluke angle, round stock stabilizers, and a large-area tripping plate attached to the flukes (see Figure 44). This anchor was pulled at 0-, and 6-deg chain angles and the HP/wt ratio was 8.51 to 1 and 7.69 to 1, respectively. The fluke angle was changed to 50 deg and re-tested at a 0-deg chain angle and the HP/wt ratio was 10.1 to 1.

The flukes of the 2900-lb anchor were fabricated with a double thickness of plate in order to increase the weight at this point and tend to drop the flukes into the mud upon initial setting. The shank was a box section formed from plate to make the shank lighter so as to tend to raise it upon initial setting in the mud. The fluke angle was 50 deg (see Figure 45). The anchor was pulled at a 0-deg chain angle only and the HP/wt ratio was 10.0 to 1. Figure 46 is a graph of the test results on the 2900-lb anchor. Results of the tests on both anchors are contained in Table 6.

CONCRETE ANCHORS. The concrete anchors, built in accordance with the Bureau of Yards and Docks instructions, consisted of one 10,500-lb wedge type (Figure 47), one 10,500-lb mushroom type (Figure 48), and four 2500-lb mushroom type (Figure 49).

The two 10,500-lb anchors and the four 2500-lb anchors were all tested[4] at 0-, and 6-deg chain angles immediately after setting, and at 0-deg chain angle after setting 24 hours and after setting in the mud 14 days. The four 2500-lb anchors were pulled in tandem, close-coupled.

Results of the tests are contained in Table 7. The 10,500-lb wedge and mushroom anchors each had a HP/wt ratio of 1.18 to 1 after setting 14 days as compared to a HP/wt ratio of .88 to 1 when pulled immediately after setting.

DISCUSSION

The fixed-fluke type of anchor has an advantage over movable fluke anchors when operating in mud bottom as no tripping device is required for the flukes. However, because of the fixed position of the flukes, it is necessary to lower the anchor to the bottom with the flukes pointed down, instead of simply dropping the anchor overboard. Lowering the anchor requires additional equipment such as a barge crane or warping tug that may not always be available.

It was apparent during the tests on the Navy steel anchors that the flukes were not opening properly in every test as the maximum and minimum holding powers varied considerably for the six test pulls. The effect of the stabilizers on the amount of anchor holding power could not be determined accurately due to this inability of the Navy stockless anchors to dig into the mud on every pull; however, it appeared likely from the data that the increase in holding power due to the addition of stabilizers was approximately 25 per cent. The stabilizer area amounted to an average of 60 per cent of the fluke area for each anchor. There appeared to be an insufficient area in the fluke tripping plates to tilt the flukes and start them into the mud. By shortening the chain length and thus providing an initial lift on the shank, the flukes tended to bury more consistently and by changing the chain angle to 6 deg the initial holding power actually increased in some instances. However, the final holding power then would decrease due to the shorter chain length and the flukes were still not successfully tripped in every test. This was apparent when the fluke angles of the anchors were fixed in open position and the holding powers were increased and were more uniform (refer to Figures 21, 22, and 23).

The anchor flukes are forced upward due to the vertical reaction of the mud against the bottom area of the flukes as they settled through the soft mud. Therefore a tripping plate with sufficient area to overcome this mud reaction against the flukes must be provided or the anchor will skid along with the flukes in a raised position.

Because of the decrease in amount of shear resistance in the mud bottom as compared with sand bottom, less force is required to bury the anchor and, therefore, the fluke angle may be larger. This was reflected in the fluke angle tests which indicated a fluke angle of 50 deg would provide the largest holding power compared to a 35-deg fluke angle for a sand bottom. The fluke angle may be varied from 50 deg to 35 deg simply by fabricating the anchor with the larger angle and inserting a wedge between the shank and the stop to reduce the angle.

The soil at the test site was termed 'mud' because of the large water content in the silty clay material that produced a low shear value. However, the mechanical composition of the soil showed 60 per cent clay content and this indicated that at a certain depth, approximately 22 ft, the material would be firmer and would result in much larger holding powers comparable to those of a 'clay' bottom. This was apparent in the tests with two Laboratory anchors, the 2770-lb Danforth anchor and the 3170-lb Baldt anchor. The design of these anchors enabled them to bury themselves to a considerable depth, as much as 24 ft for the 2900-lb Laboratory anchor and, therefore, the resulting holding powers are not to be compared in the strict sense with 'mud' bottom holding powers. However, the ability of anchors of this design to penetrate soft mud layers and to bury into firmer underlying strata are additional advantages as the holding power is dependent upon the moment of the projected fluke area plus the stabilizer area about the ground surface. Figure 50 is a graph of the test results showing this relationship.

CONCLUSIONS

The following conclusions are based on results of tests conducted in mud and sand bottoms. They do not apply to the anchors tested here nor to similar anchors under dissimilar bottoms such as marl or rock.

The Navy stockless anchor may be prevented from rotating by addition of the BuDocks-designed steel-plate stabilizer welded in a position normal to the flukes. This stabilizer will provide a more uniform holding power for the anchor and will increase the holding power in mud bottoms slightly and approximately 10 per cent in sand. Stabilizers are required in mud after the anchors have buried sufficiently to encounter a soil reaction that produces a rotational torque on the anchor.

Changing the fluke angle from 35 deg to 50 deg increased the holding power approximately 100 per cent.

The ratio of holding power to weight of the 7500-lb concrete-steel anchor, 2.92 to 1, is comparable to the ratio for the stabilized Navy steel anchors in mud, 3.31 to 1. These similar ratios are due to the small fluke angle, 28 deg, on the 7500-lb anchor. The fixed position of the shank on the 7500-lb anchor would be a marked disadvantage if the anchor was to be utilized both mud and sand bottoms.

The break-out forces for the Laboratory and Danforth anchors were larger than for the stockless anchors because of the additional depth of burial. The break-out force tended to vary directly with the final holding powers.

The anchors having relatively long thin flukes and least restriction to burial, such as the Laboratory, new Baldt, Croseck, Danforth and Lightweight anchors, produced the larger HP/wt ratios.

Fixing the flukes of the steel Navy anchors in an open position increases the holding power but requires the anchor to be initially set in an upright position.

Design criteria for a mooring anchor operating in a mud bottom as determined from these tests would be as follows:

a. Lightweight, fabricated from steel plate.
b. Two flukes which can rotate to a 50-deg angle from the shank. Fluke area of the anchor to be dependent upon the required holding power. Length and width of the flukes to be proportioned to produce the maximum moment or holding power.
c. A fluke tripping plate of sufficient area and slope to overcome the resistance of the mud on the lower side of the flukes upon initial setting.
d. Obstruction to anchor burial to be restricted to a minimum.
e. Adequate-size stabilizers to prevent rotation of the anchor.

RECOMMENDATIONS

It is recommended that stabilizers be added to Navy stockless anchors which are to be used in moorings or ground tackle in a mud bottom.

Because of the size of the stabilizers and the added shipping cubage involved, the stabilizers should be stored and shipped as separate items from the anchors.

It is recommended that a group or 'family' of low-cost, lightweight mooring anchors be developed to cover the entire range of required holding powers.

Design criteria for these mooring anchors should be based on the results of the sand and mud bottom tests.

REFERENCES

1. NAVCERELAB Technical Memorandum M-066, Test of Anchors for Moorings and Ground Tackle Design, by R.C. Towne, 10 June 1953.

2. Bureau of Yards and Docks Technical Publication NAVDOCKS TP-PW-2 MOORING GUIDE, Volume 1, 1 March 1954.

3. NAVCERELAB Technical Note N-195, Tests of BuShips Anchors in Mud and Sand Bottoms, by R.C. Towne and J.V. Stalcup, 5 August 1954.

4. Bureau of Yards and Docks Addendum to Testing Procedure, Suggested Testing Procedure for Determining Safe Holding Power of Concrete Anchors - Wedge and Mushroom Types.

TABLE 1. Soil Analysis Data

Hole No.	Sample No.	Elev. depth	Unit weight (dry lb/cu ft)	Moist. content (% dry weight)	Unconfined compression (ton/sq ft)
1	1	4	72	99.6	collapsed under own wt
	2	5	73	94.7	collapsed under own wt
	3	10	77	47.1	collapsed under own wt
	4	15	74	73.7	.0732
	5	15.5	75	68.8	.0488
	6	16	75	69.0	.0732
	7	20	75	76.1	.0488
	8	20.5	75	82.6	.0793
	9	21	75	70.9	.0976
	10	24	75	71.1	.0975
	11	24.5	76	69.6	.1219
	12	25	76	74.6	.1077
2	1	5	72	105.6	collapsed under own wt
	2	9	72	129.3	.0244
	3	9.5	74	81.8	.0317
	4	10	74	75.[illegible]	.0366
	5	14	73	77.2	.0427
	6	14.5	74	81.5	.0390
	7	15	75	78.3	.0427
	8	19.5	74	81.5	.0367
	9	20	75	70.0	.0402
	10	24.5	75	71.3	.0390
	11	25	75	67.7	.0975
3	1	21.5	73	103.0	collapsed under own wt
	2	22	74	90.9	collapsed under own wt
	3	22.5	74	102.8	collapsed under own wt
	4	23	75	88.7	collapsed under own wt
	5	23.5	76	77.9	.0244
	6	24	74	91.1	collapsed
	7	24.5	75	81.8	.0293
	8	25	73	78.1	.0220
	9	25.5	74	79.4	.0242
	10	26	75	82.5	.0348

TABLE 1. (contd)

Hole No.	Sample No.	Elev. depth	Unit weight (dry lb/cu ft)	Moist. content (% dry weight)	Consolidation % original ht (ton/sq ft)						Direct cohesion (psi)	Shear angle of internal friction
					1/4	1/2	1	2	4	8		
1	1	20-22	78	64.5							0.41	7
2	1	22	79	64.2							0.432	5
3	1	20-22	82	64.9	11	16	21	26	32	37		
	3	20-22	81	60.0	11	16	21	27	34	40		
	2	20-22	79	61.0							0.41	5

Hole Nos. 1 and 2 composite - liquid limit: 62; plasticity index: 34
Hole No. 3 composite of samples 1,2,3 - liquid limit 57; plasticity index: 28
Hole Nos. 1,2,3, sample No. 1 - specific gravity: 2.72

TABLE 2. Anchor Stabilizers

Anchor	Wt (lb)	Stabilizers length	Stabilizers width	Stabilizers thickness
Navy stockless	1500	21	6	1/2
Navy stockless	3000	30	13	1/2
Navy stockless	6000	42	16	1/2
Navy stockless	10000	3[illegible]	19	3/4
Navy stockless	20000	45	21	1
Navy stockless	30000	50	23	1
Danforth	2510	51.5	4 1/2 round	
Danforth	2770	51.5	4 1/2 round	
Danforth	4000	56	5 round	
Danforth	10000	62.5	5 1/2 round	
Danforth	12000	82.0	10 round	
Laboratory	1620	36	3 1/2 round	
Laboratory	2900	48	3 1/2 round	
Concrete-steel	7500	30	12	1
Baldt	3170	18	29	3
Baldt	3650	15	3 round	
Croseck	3060	24	4 1/2 round	
BuDocks 'straight'	1430	18	9	1
BuDocks 'curved'	1430	24	9	1
Lightweight	500	23	2 round	
Lightweight	1000	29	2 1/2 round	
Lightweight	2000	36	3 round	
Lightweight	3000	46	3 1/2 round	
Lightweight	4000	46	4 1/4 round	
Lightweight	10000	56	5 1/2 round	

TABLE 3. Holding Power Data of Navy Stockless Anchors Tested in Mud Bottom

Anchor	Wt (lb)	Stab-ilizer	Fluke angle	Average holding power			Depth of embd.[1]	Minimum holding power			Chain angle (deg)	HP/wt-ratio[2]	Average breakout force
				50-ft	100-ft	150-ft		50-ft	100-ft	150-ft			
Navy stockless	1500	w/o	41	6700	6800	7500	2	4800	4800	4800	0	4.46	1800
Navy stockless	1500	w		8400	8700	7600	5	4800	6700	3800	0	5.60	5100
Navy stockless	1500	w		6800	7300	7300	6	3800	5700	5700	6	4.53	6000
Navy stockless	1500	w		5800	6300	7300	5	4800	4800	4800	12	3.83	5400
Navy stockless	3000	w/o	49	12200	12900	13400	3	7700	8600	9600	0	4.06	4400
Navy stockless	3000	w		14300	14800	16200	6	11500	10500	12400	0	4.76	12900
Navy stockless	3000	w		14500	15600	15400	6	11500	11500	11500	6	4.83	10900
Navy stockless	3000	w		14000	14200	15000	5	10500	11500	12400	12	4.66	10000
Navy stockless	6000	w/o	47	11000	11800	11400	-	5700	6600	7600	[illegible]	1.83	16000
Navy stockless	6000	w		17100	19400	22400	6	11400	13300	15300	0	2.85	14000
Navy stockless	6000	w		14900	15800	17500	5	9500	11400	9500	6	2.48	...
Navy stockless	6000	w		8700	10900	11900	4	5700	7600	9500	12	1.45	...
Navy stockless	10000	w/o	[illegible]	15200	16300	17300	8	15200	16300	17300	0	1.52	28500
Navy stockless	10000	w		24300	28000	30800	6	19100	18100	19100	0	2.42	...
Navy stockless	10000	w		24200	26300	27100	6	21000	23900	24800	6	2.42	...
Navy stockless	10000	w		17000	17100	[illegible]	4	11400	10500	13300	12	1.70	...
Navy stockless	20000	w/o	47	43700	51700	60900	6	20100	23900	33500	0	2.18	48500
Navy stockless	20000	w		44400	51500	53400	7	39200	45900	45900	0	2.22	50000
Navy stockless	20000	w		48000	57800	60400	6	26800	32500	40200	6	2.40	57300
Navy stockless	20000	w		46400	49900	54200	6	30600	34400	30600	12	2.32	53200
Navy stockless	30000	w/o	45	59000	77700	84200	13	48600	66400	66400	0	1.96	63500
Navy stockless	30000	w		61000	78100	93700	14	40100	44000	56100	0	2.03	57300
Navy stockless	30000	w		53100	64100	70400	17	43000	55200	60800	6	1.77	47400
Navy stockless	30000	w		61900	82700	90200	19	58000	69200	72900	12	2.06	54500

[1] Average depth of anchor embedment into the mud at completion of test pulls

[2] Average holding power at 50-ft/anchor weight in air

TABLE 4. Holding Power Data of Navy Steel Anchors With Fixed Flukes

Anchor	Wt (lb)	Fluke angle	Average holding power			Depth of embd.	Minimum holding power			Chain angle (deg)	HP/wt-ratio 50-ft	Average breakout force
			50-ft	100-ft	150-ft		50-ft	100-ft	150-ft			
Navy stockless w/stab.	6000	47	21000	26000	29000	8	17000	19000	22000	0	3.5	19000
Navy stockless w/stab.	10000	45	49000	59000	60000	11	44000	54000	50000	0	4.9	38000
Navy stockless w/stab.	20000	47	86000	106000	119000	15	75000	100000	109000	0	4.3	75000

TABLE 5. Holding Power Data of Steel Anchors Tested in Mud Bottom at Hunters Point

Anchor	Wt (lb)	Fluke angle	Average holding power length of drag 50-ft	100-ft	150-ft	Depth of embd.	Minimum holding power length of drag 50-ft	100-ft	150-ft	Chain angle (deg)	Holding power anchor wt ratio	Average breakout force
Concrete-steel	7500	28	21900	25300	28300	10.0	19100	22900	23900	0	2.92	19000
Concrete-steel	7500	...	17500	23400	24600	...	14300	19100	2100	6	2.33	47000
Concrete-steel	7500	...	16700	22200	24500	...	12400	15300	21000	12	2.22	...
BuDocks 'straight'	1430	180	3200	3800	3900	...	2300	2500	2800	0	2.23	...
BuDocks 'curved'	1430	180	3500	3700	3700	...	3300	3700	3500	0	2.44	...
Baldt new design	3170	50	21000	30200	25400	13.0	12100	14000	13100	0	6.62	17400
Baldt new design	3650	50	12800	14900	16600	8.0	9300	8400	8400	0	3.50	7700
Crosack	3060	51	23500	35600	41200	18.0	14300	21000	26000	0	7.67	17300
Lightweight	500	29	1600	1700	1800	...	1200	1500	1500	0	3.20	...
Lightweight	500		1400	1500	1400	...				6	2.80	...
Lightweight	500		1500	1800	2100	...	1300	1500	2000	12	3.00	...
Lightweight	1000	30	3500	4100	5100	7.0	3000	4000	4300	0	3.50	5600
Lightweight	1000		3100	4100	4900	7.0	2700	3500	4300	6	3.10	4200
Lightweight	1000		2700	2800	3300	...	2200	2300	2700	12	2.70	...
Lightweight*	2000	29	7500	7900	8800	7.0	5000	5700	6500	0	3.75	5300
Lightweight*	2000		5400	6700	7400	4.0	4200	5300	5500	6	2.70	3500
Lightweight*	2000		5800	6800	7600	5.0	4800	5700	5700	12	2.90	3300
Lightweight*	3000	30	11700	12600	13000	13.0	8600	8600	8600	0	3.90	8900
Lightweight*	3000		10000	12600	12900	10.0	7700	8600	11500	6	3.33	7500
Lightweight*	3000		8400	10200	11100	14.0	4800	6700	7700	12	2.80	8300
Lightweight*	4000	30	11400	13200	15700	9.0	7700	9600	11500	0	2.85	7400
Lightweight*	4000		8700	13500	13800	8.0	5700	9600	9600	6	2.17	6200
Lightweight*	4000		9500	12200	14300	7.0	6700	8600	9600	12	2.37	9700
Lightweight*	10000	30	18800	20900	21100	5.0	13100	17700	10700	0	1.88	12700

*Reference BuShips anchor tests[3]

TABLE 6. Holding Power Data of Steel Anchors Tested in Mud Bottom at Hunters Point

Anchor	Wt (lb)	Fluke angle	Average holding power length of drag 50-ft	100-ft	150-ft	Depth of Embd.	Minimum holding power length of drag 50-ft	100-ft	150-ft	Chain angle (deg)	Holding power anchor wt ratio	Average breakout force
Danforth	165		2100	2500	2600	...	1800	1800	2000	0	12.72	...
Danforth	2510	32	22100	26900	29100	20.0	17200	20100	27600	0	8.91	24000
Danforth	2510		20500	24500	28700		17200	21100	22000	6	8.26	22700
Danforth	2510		19400	21000	22900		16300	17200	20100	12	7.82	22400
Danforth	2770	34	2[illegible]900	31200	36000	20.0	23900	25800	28700	0	9.92	15800
Danforth	2770		[illegible]	25800	29400	11.0	19100	19100	22000	6	8.07	...
Danforth	2770		19400	24300	24600	14.0	15300	17200	17200	12	6.92	...
Danforth	4000	35	15600	15700	15900	4.0	13300	15300	15300	0	3.90	...
Danforth	4000		12500	12500	12600	4.0	11400	11400	11400	6	3.12	...
Danforth	4000		11400	12200	13100	3.0	7600	9500	10500	12	2.85	...
Danforth	10000	34	30600	36200	37700	9.0	13400	28700	30600	0	3.06	27000
Danforth	10000		28300	31500	34600	12.0	23000	27800	30600	6	2.88	36000
Danforth	10000		25200	27900	29800	10.0	20100	22000	25800	12	2.52	28500
Danforth	12000	36	49400	61500	75200	25.0	40200	56500	63200	0	3.70	65600
Danforth	12000		46200	73500	89900	25.0	32500	54500	73600	6	3.46	63400
Danforth	12000		49300	58700	72300	19.0	47800	52600	67900	12	3.69	50000
Laboratory	1620	50	16500	18000	17500	11.0	14300	17000	16200	0	10.10	12300
Laboratory	2900	50	29200	42600	51400	20.0	21500	34600	49600	0	10.00	20000

TABLE 7. Holding Power Data of Concrete Anchors Tested In Mud Bottom at Hunters Point

Anchor	Wt (lb)	Average holding power length of drag			Minimum holding power length of drag			Chain angle (deg)	Holding power anchor wt ratio	Time of anchor set
		50-ft	100-ft	150-ft	50-ft	100-ft	150-ft			
Concrete-mushroom	2500	8800	9300	10500	7700	8600	9600	0	0.88	...
Concrete-mushroom	2500	7400	8800	8300	6700	8600	6700	6	0.74	...
Concrete-mushroom	2500	10500	9600	...	...	...	...	0	1.05	2 days
Concrete-mushroom	2500	10500	11500	...	...	...	...	0	1.05	19 days
Concrete-wedge	10500	9300	11900	11700	8600	10500	10500	0	0.88	...
Concrete-wedge	10500	9600	10700	10300	7700	9600	8600	6	0.93	...
Concrete-wedge	10500	11500	15300	...	...	...	...	0	1.09	1 day
Concrete-wedge	10500	12400	10500	...	...	...	...	0	1.18	14 days
Concrete-mushroom	10500	9100	10000	13300	8600	9600	11500	0	0.56	...
Concrete-mushroom	10500	79[illegible]	8600	10000	6700	6700	6700	6	0.75	...
Concrete-mushroom	10500	15300	13400	...	...	...	...	0	1.45	1 day
Concrete-mushroom	10500	12400	14400	...	...	...	...	0	1.18	14 days

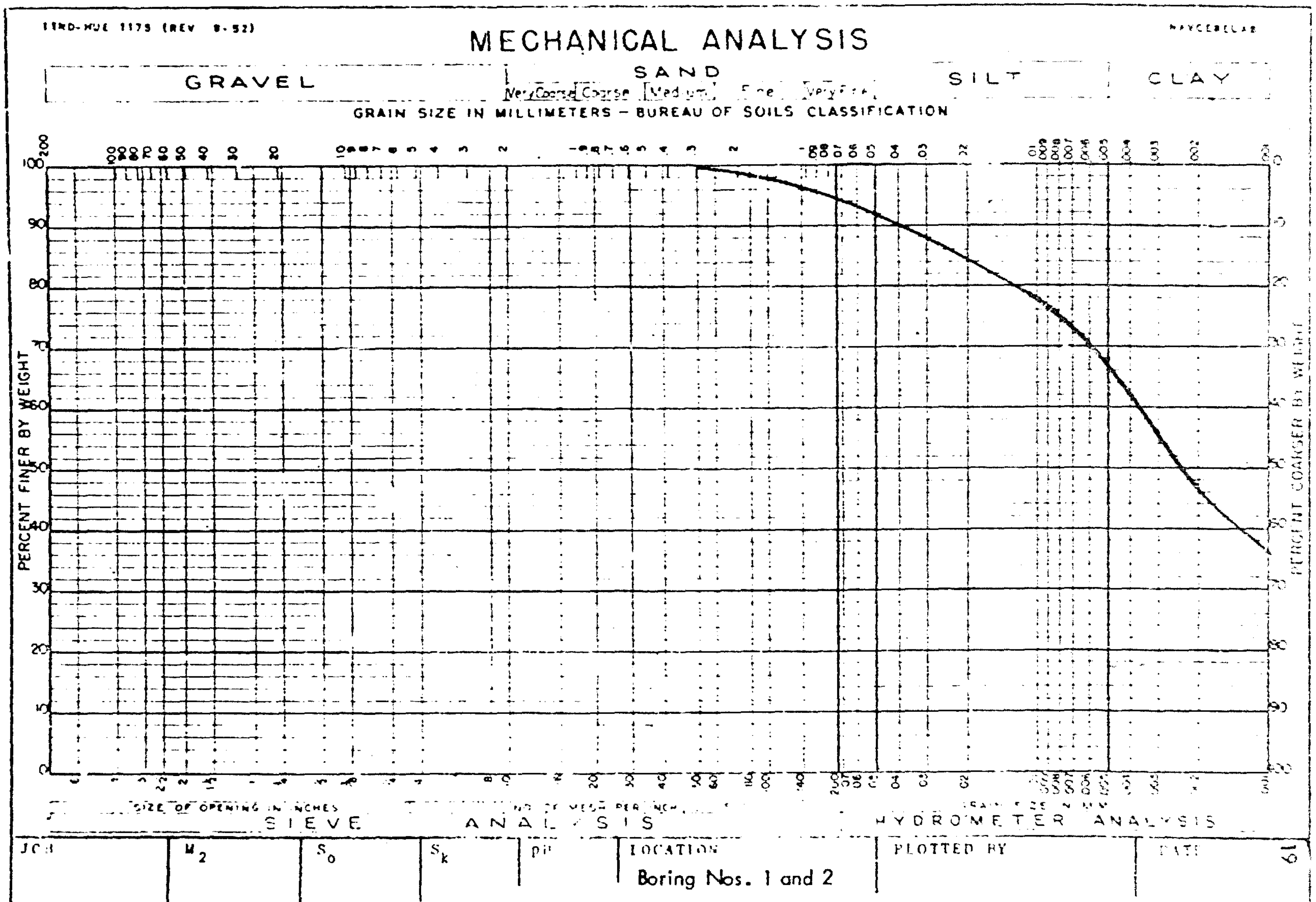


Figure 2. Mechanical analysis of soil at test site

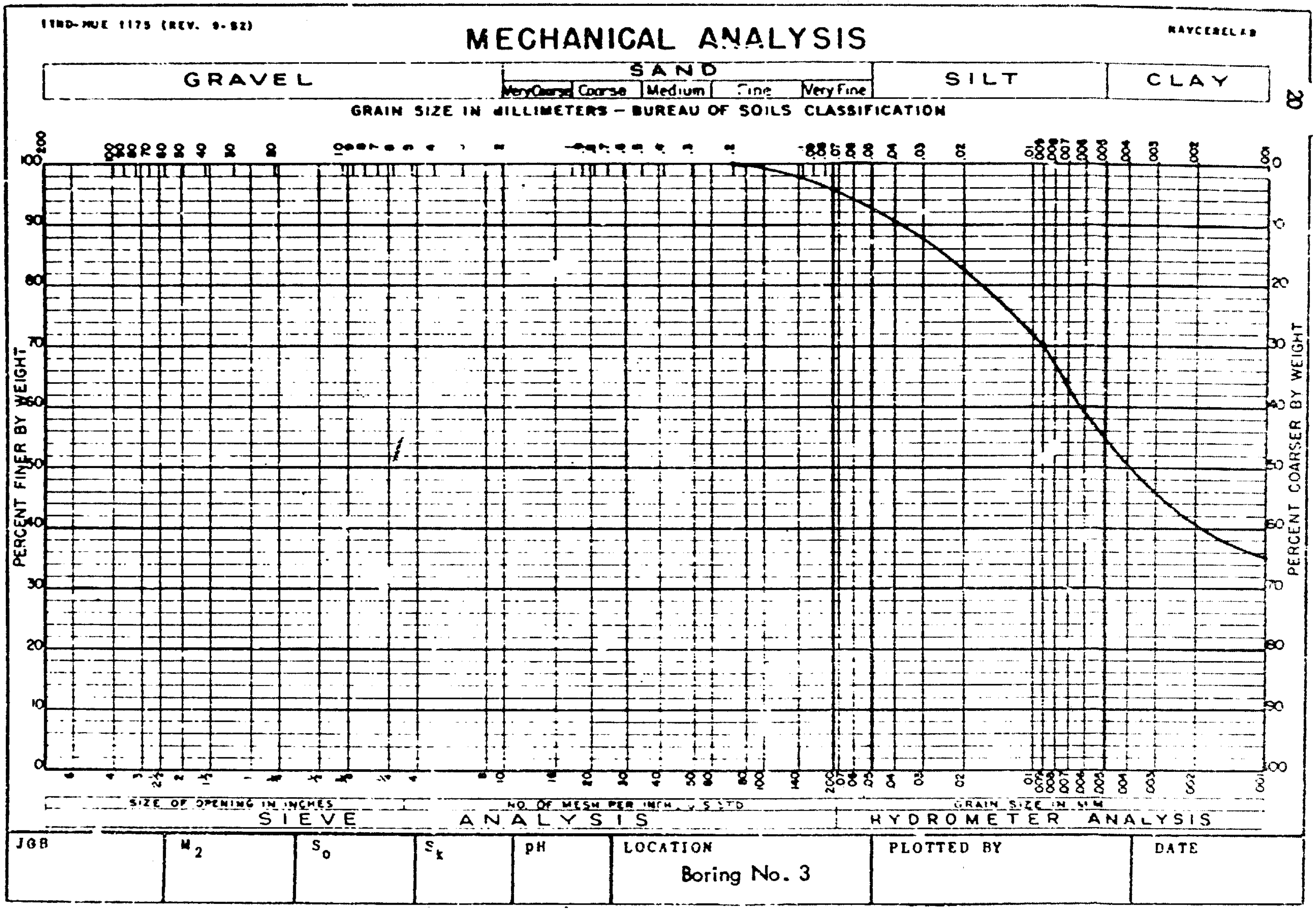


Figure 3. Mechanical analysis of soil at test site

Consolidation data   Hole No. 3   Sample No. 1   Depth 20 to 22 ft

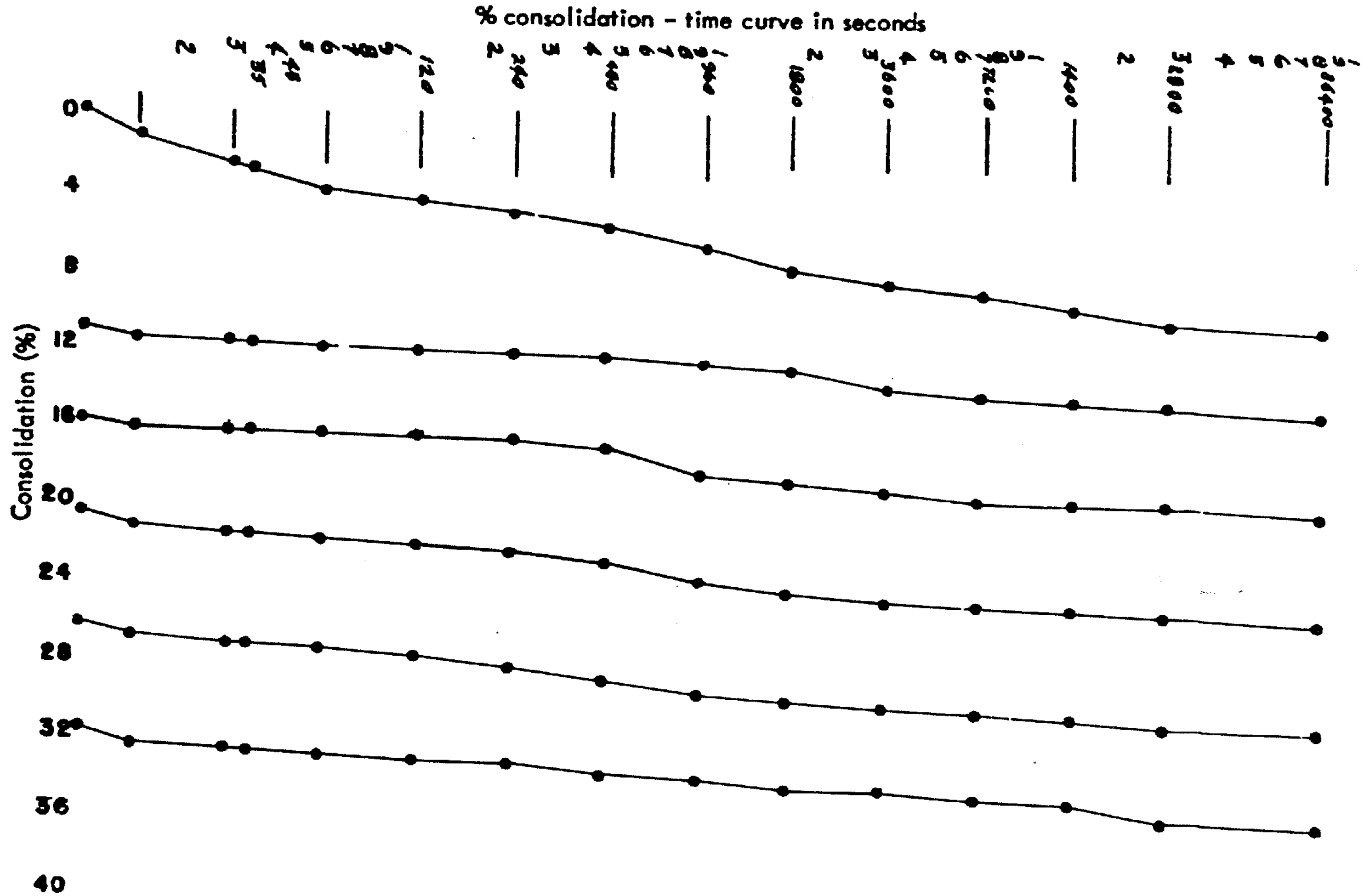


Figure 4. Soil analysis

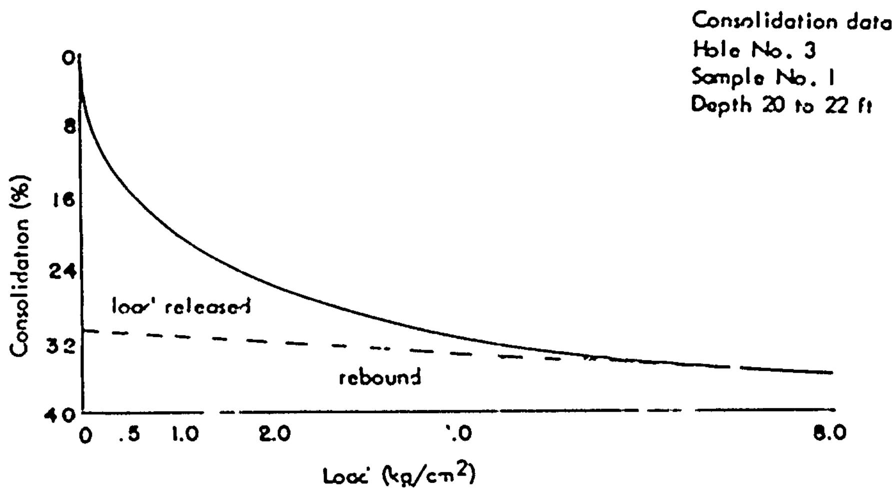


Figure 5. Soil analysis

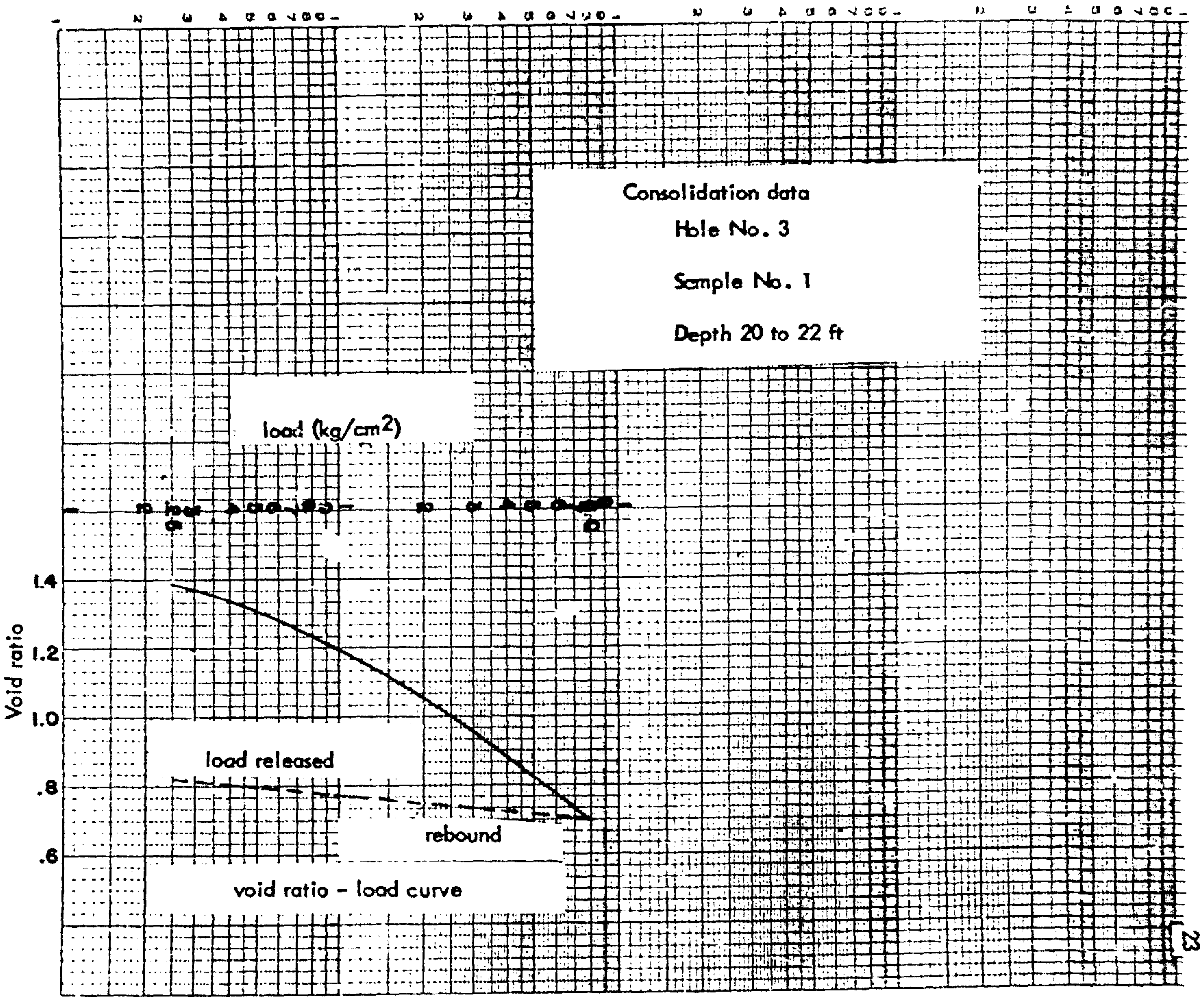


Figure 6. Soil analysis

Consolidation data Hole No. 3 Sample No. 3 Depth 20 to 22 ft

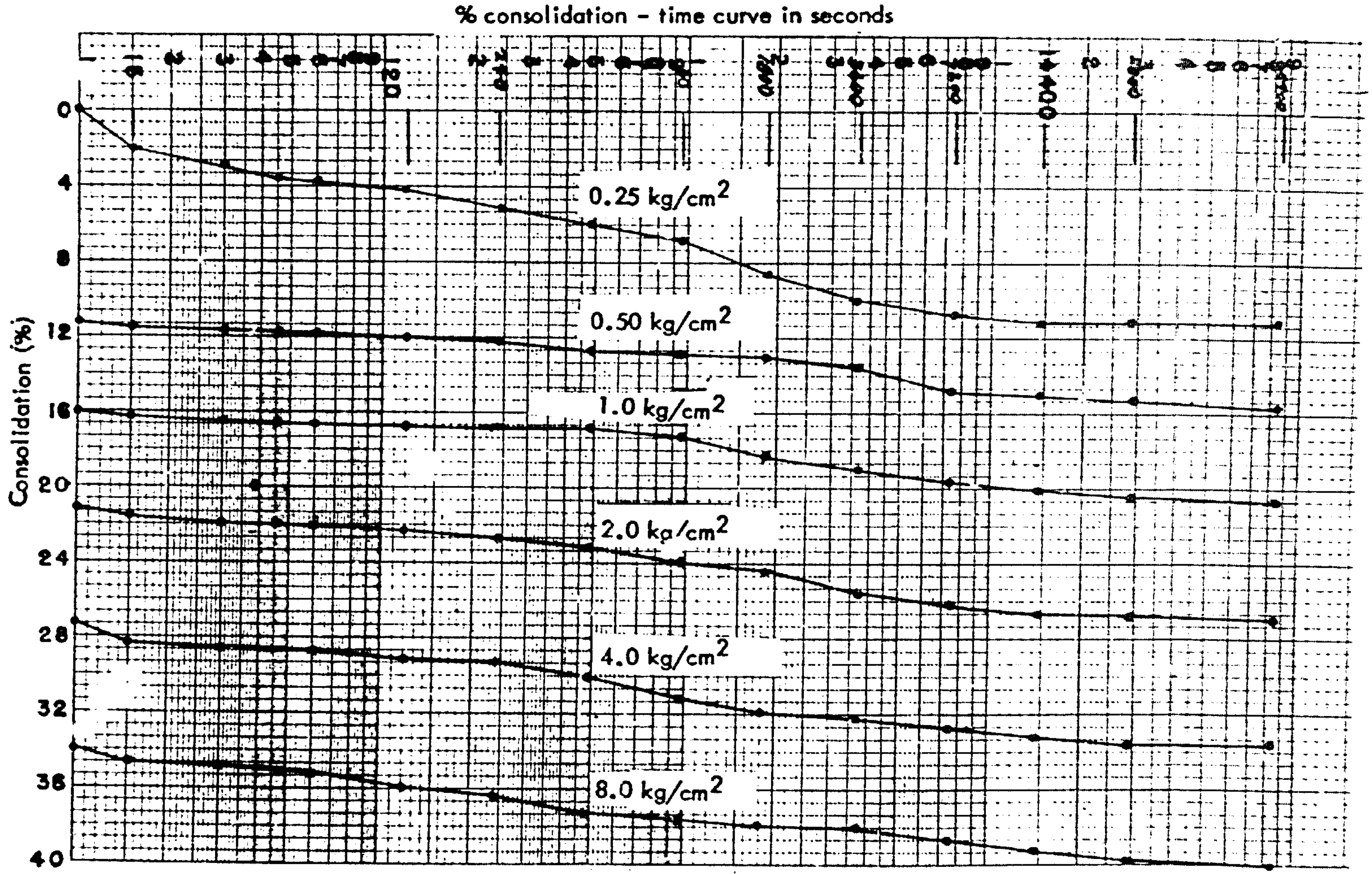


Figure 7. Soil analysis

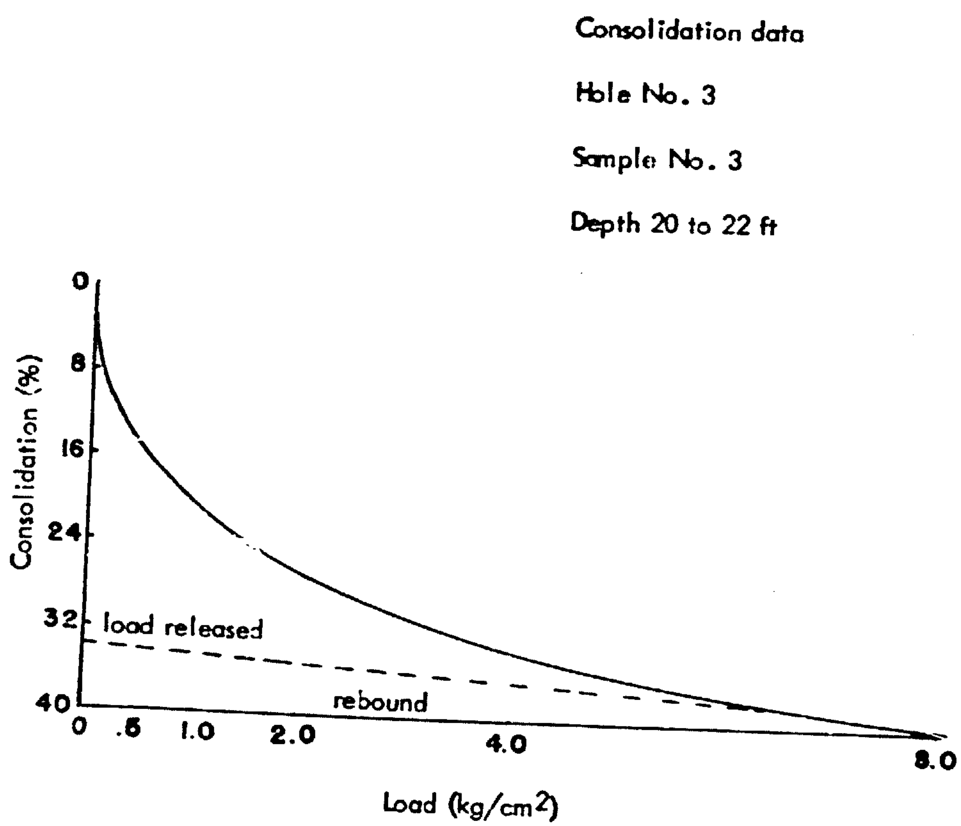


Figure 8. Soil analysis

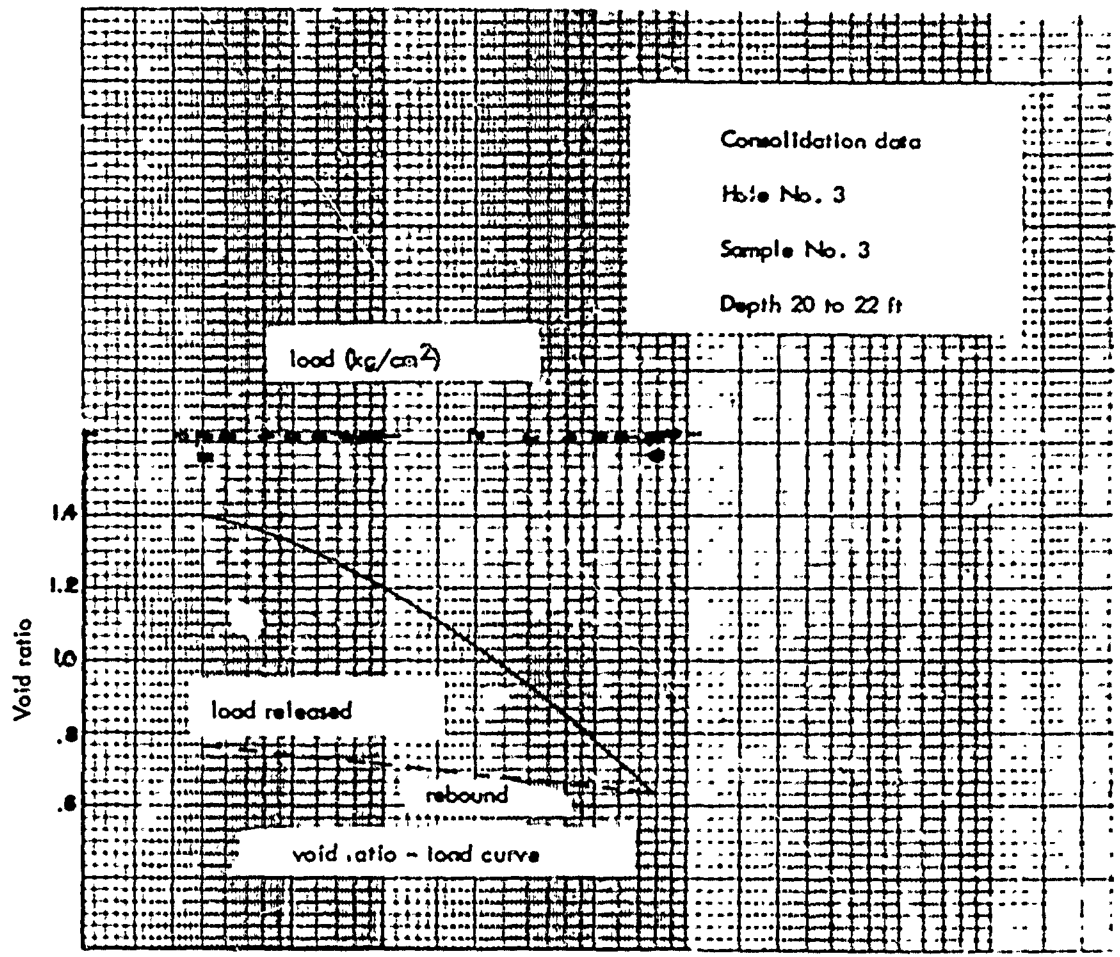


Figure 9. Soil analysis

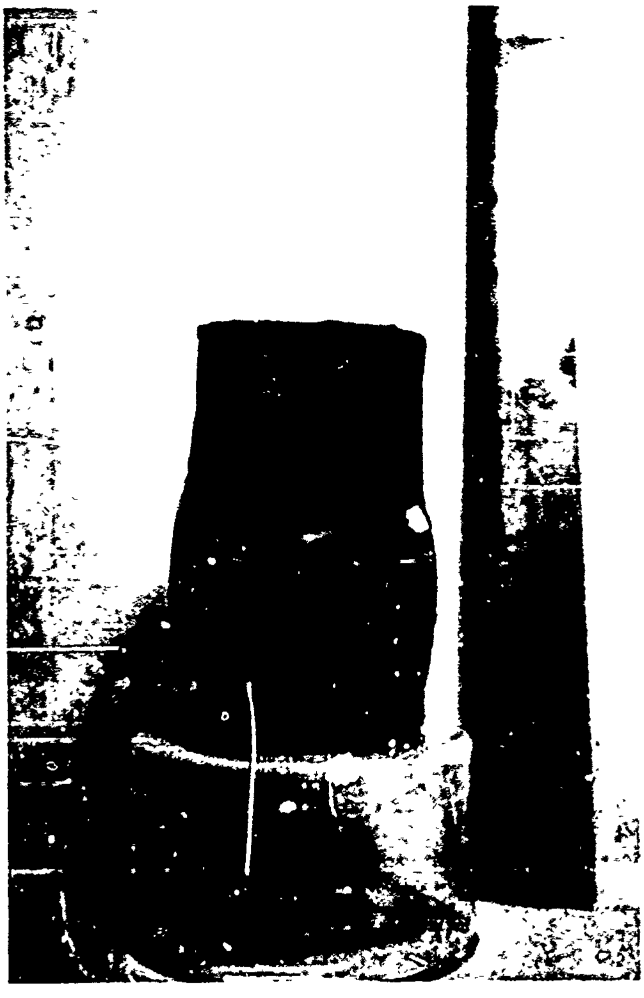


Figure 10. Unconfined compression test failure

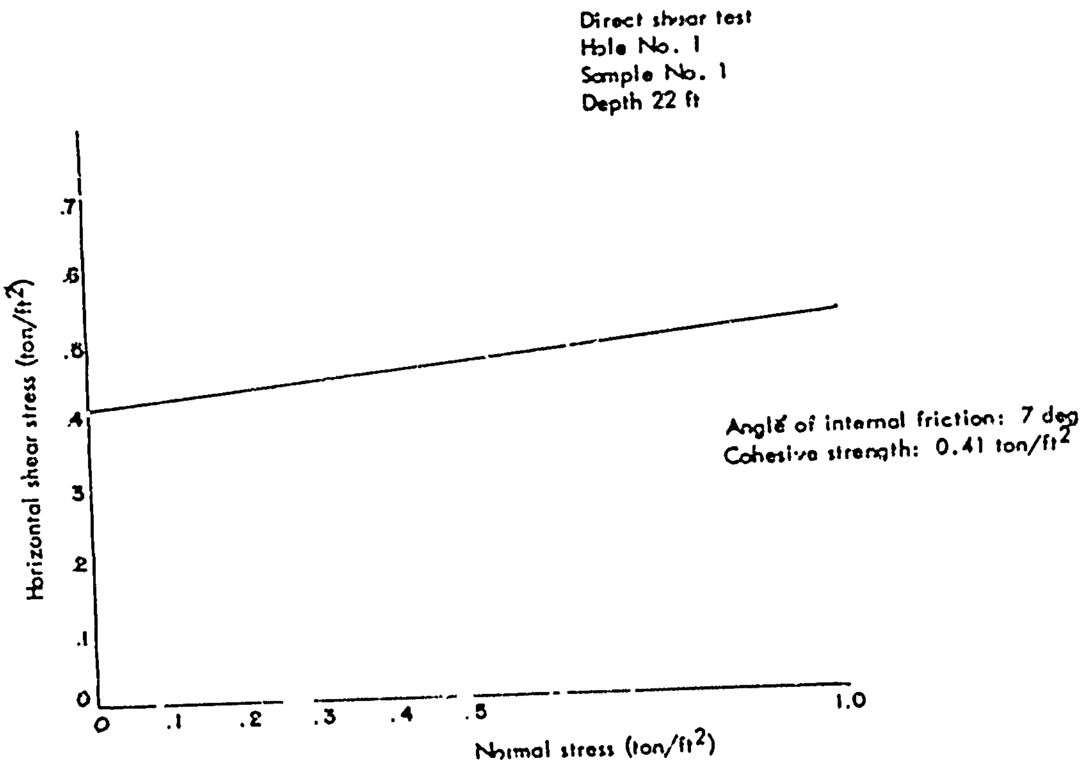


Figure 11. Direct shear test of soil

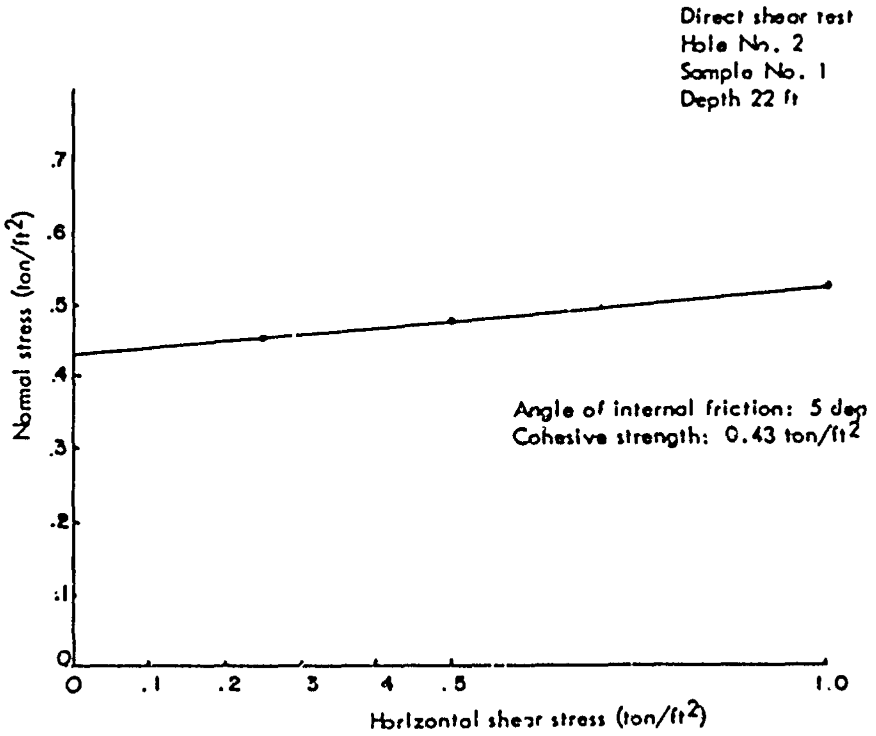


Figure 12. Direct shear test of soil

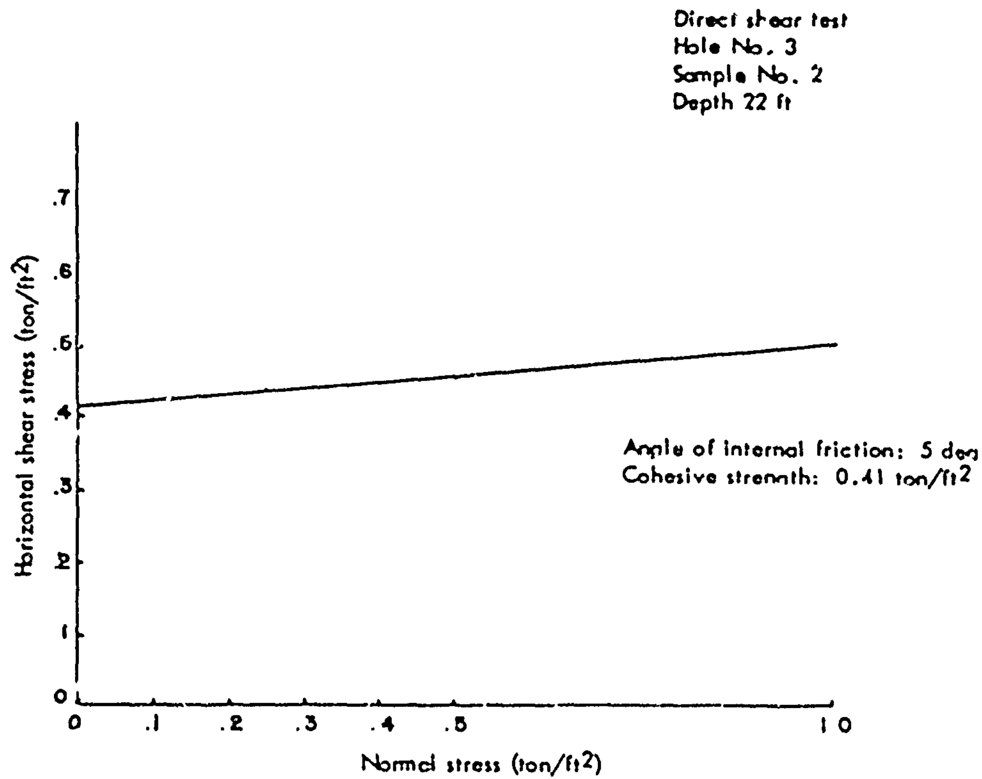
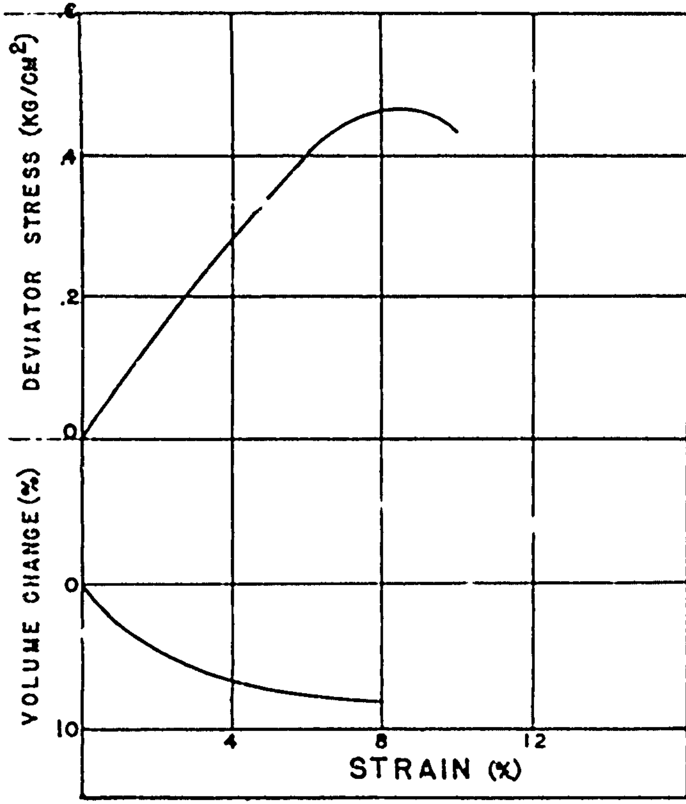
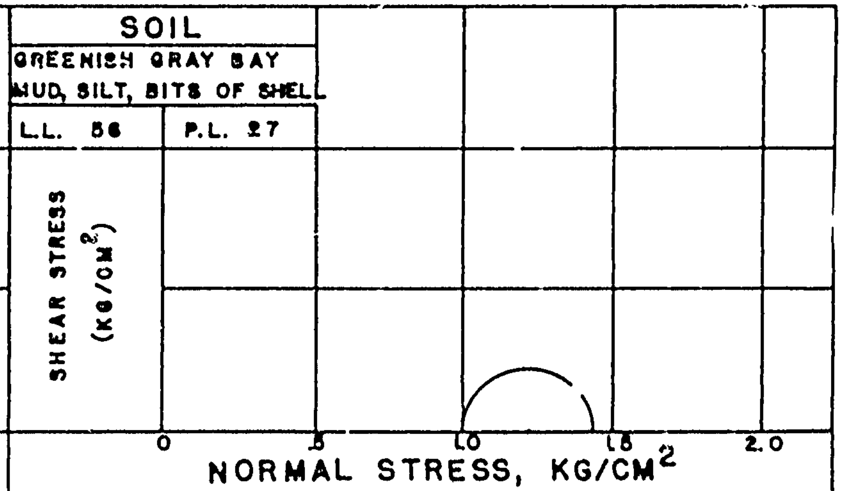


Figure 13. Direct shear test of soil





SOIL	
GREENISH GRAY BAY MUD, SILT, BITS OF SHELL	
L.L. 56	P.L. 27

CURVE Nº	RATE OF SHEAR		LATERAL PRESSURE KG/CM^2	SPECIMEN PREPARED AT	
	TOTAL TIME MIN	AVERAGE % PER MIN		DRY WT LB/CF	MOISTURE PER CENT
1	9	.05	1.0	76.9	57.1

INITIAL		FINAL	SPECIMEN DATA			
MOISTURE PER CENT	SATURATION PER CENT	MOISTURE PER CENT	HT IN.	DIA IN.	MAXIMUM PARTICLE SIZE	G
61.2	100	61.2	4.95	2.5	Nº 40	2.72

TYPE OF TEST:
CONSOLIDATED, UNDRAINED

LATERAL PRESSURE METHOD:
HYDRAULIC

CONDITION:
UNDISTURBED

Triaxial shear test
Hole No. 3
Sample No. 2
Depth 20 to 22 ft

Figure 14. Triaxial shear data on soil

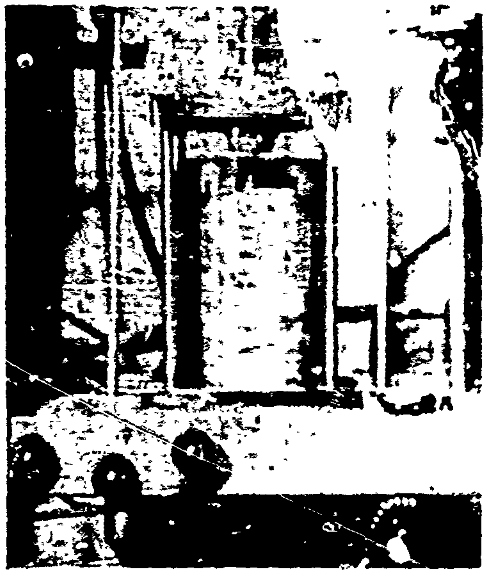


Figure 15. Triaxial shear test failure

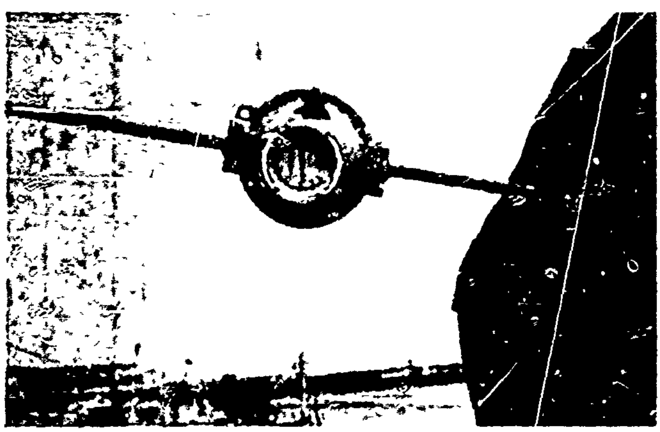


Figure 16. Strain gage used to measure break-out force of anchors

Figure 17. Typical Navy stockless anchor

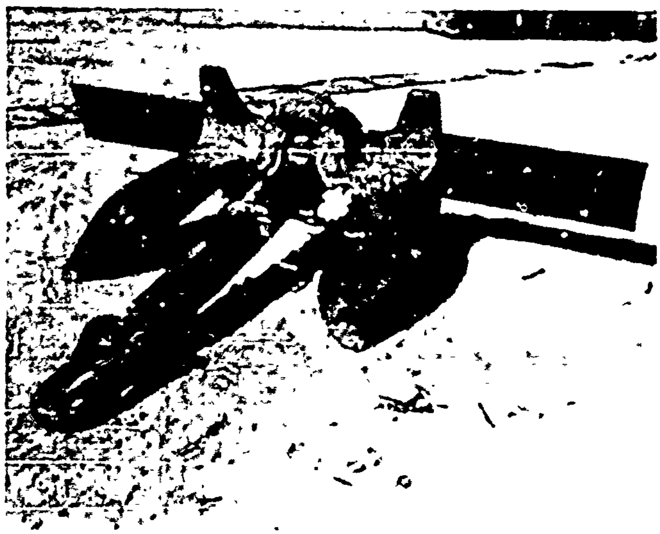


Figure 18. Typical stabilized Navy anchor

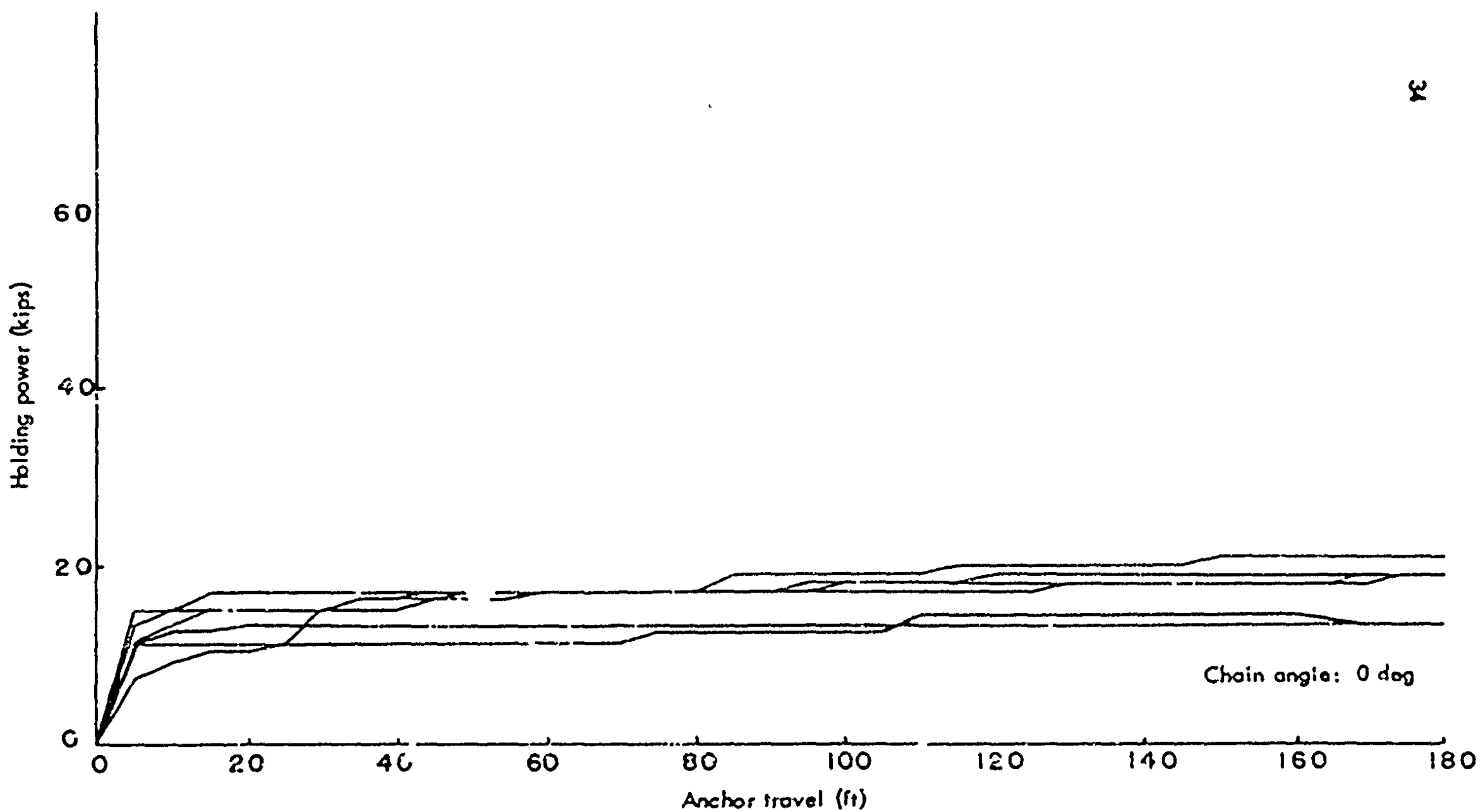


Figure 19. Graph of test pulls on 10,000-lb Navy steel anchor without stabilizers

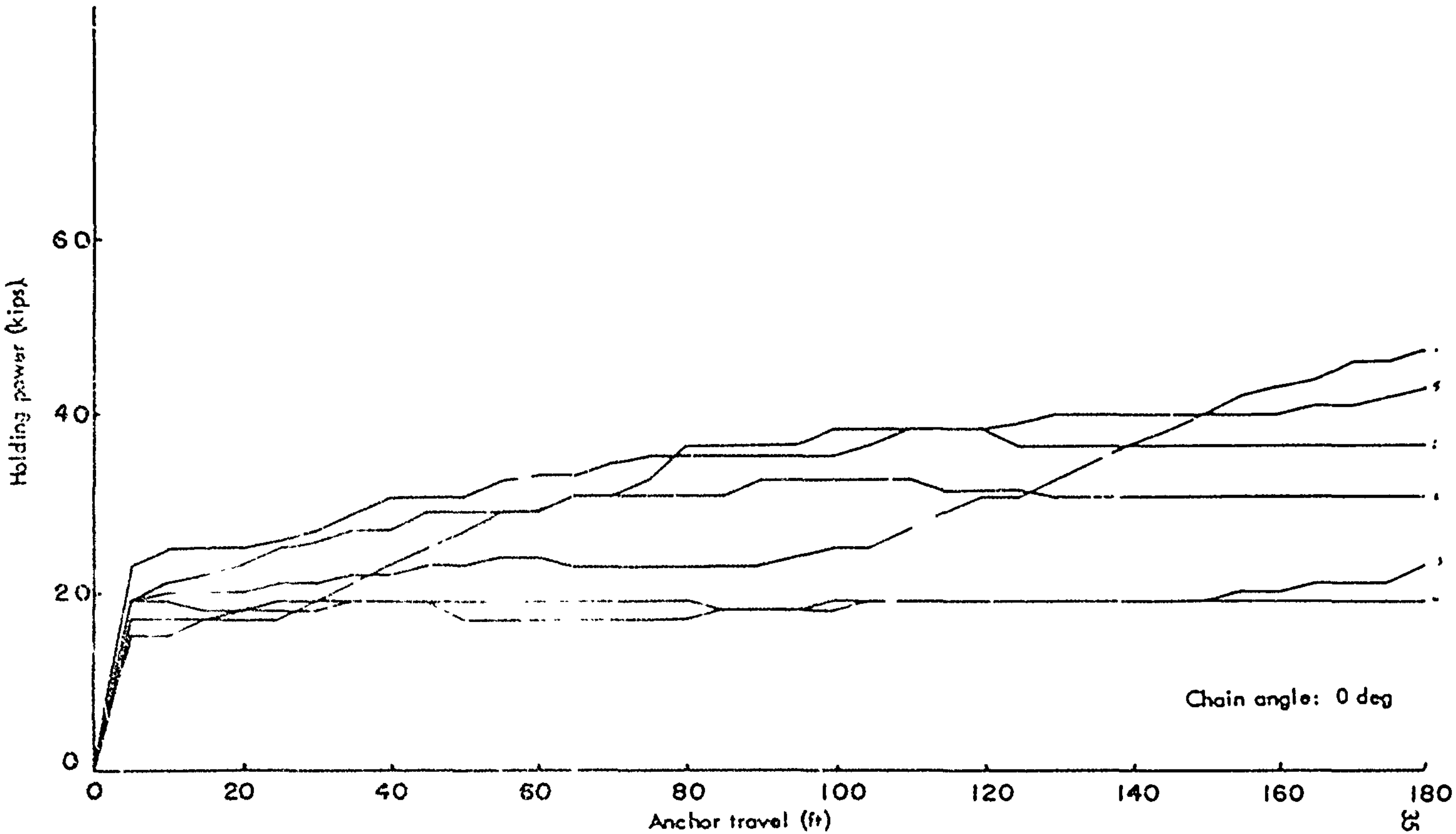


Figure 20. Graph of test pulls on 10,000-lb Navy steel anchor with stabilizers

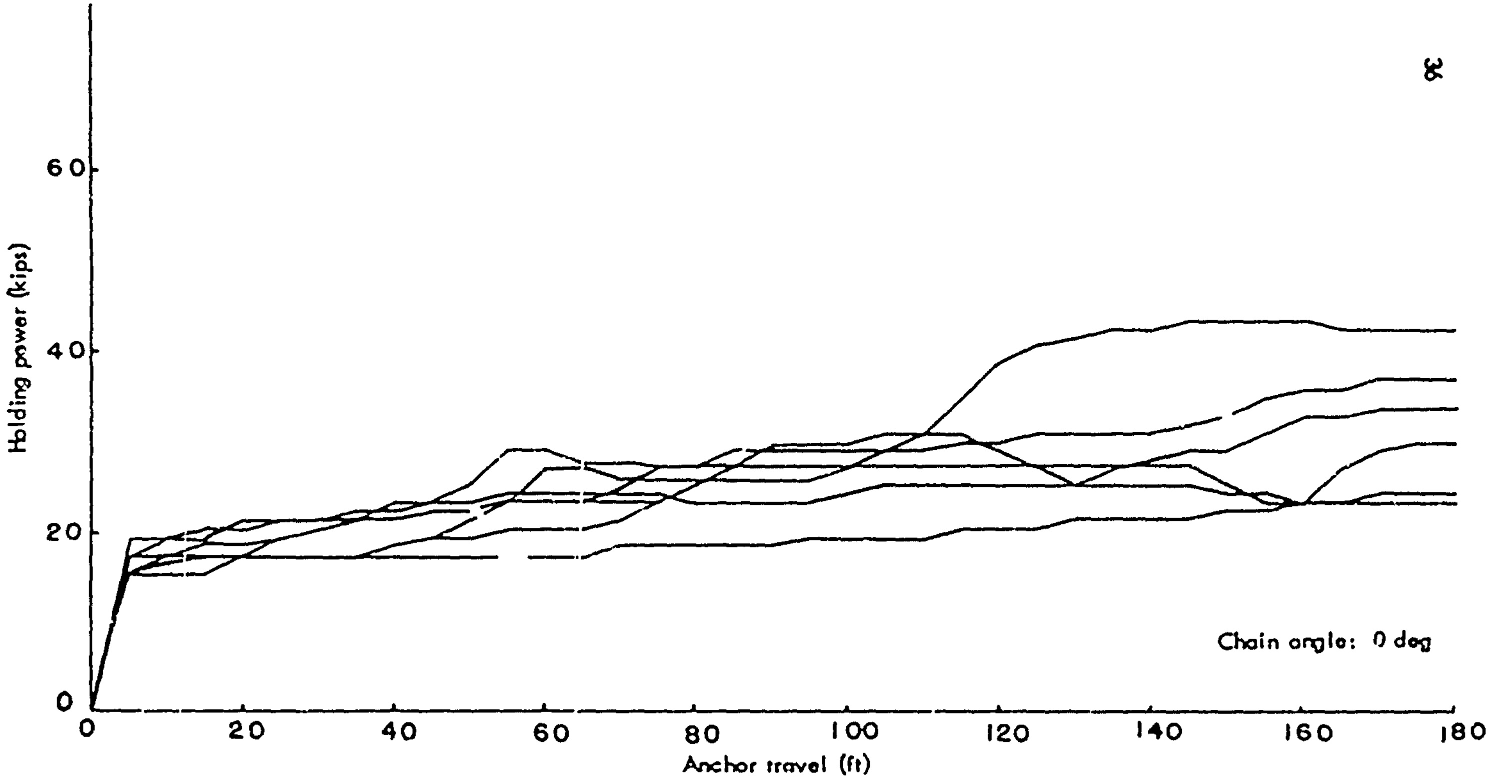


Figure 21. Graph of test pulls on 6000-lb Navy steel anchor with fixed flukes

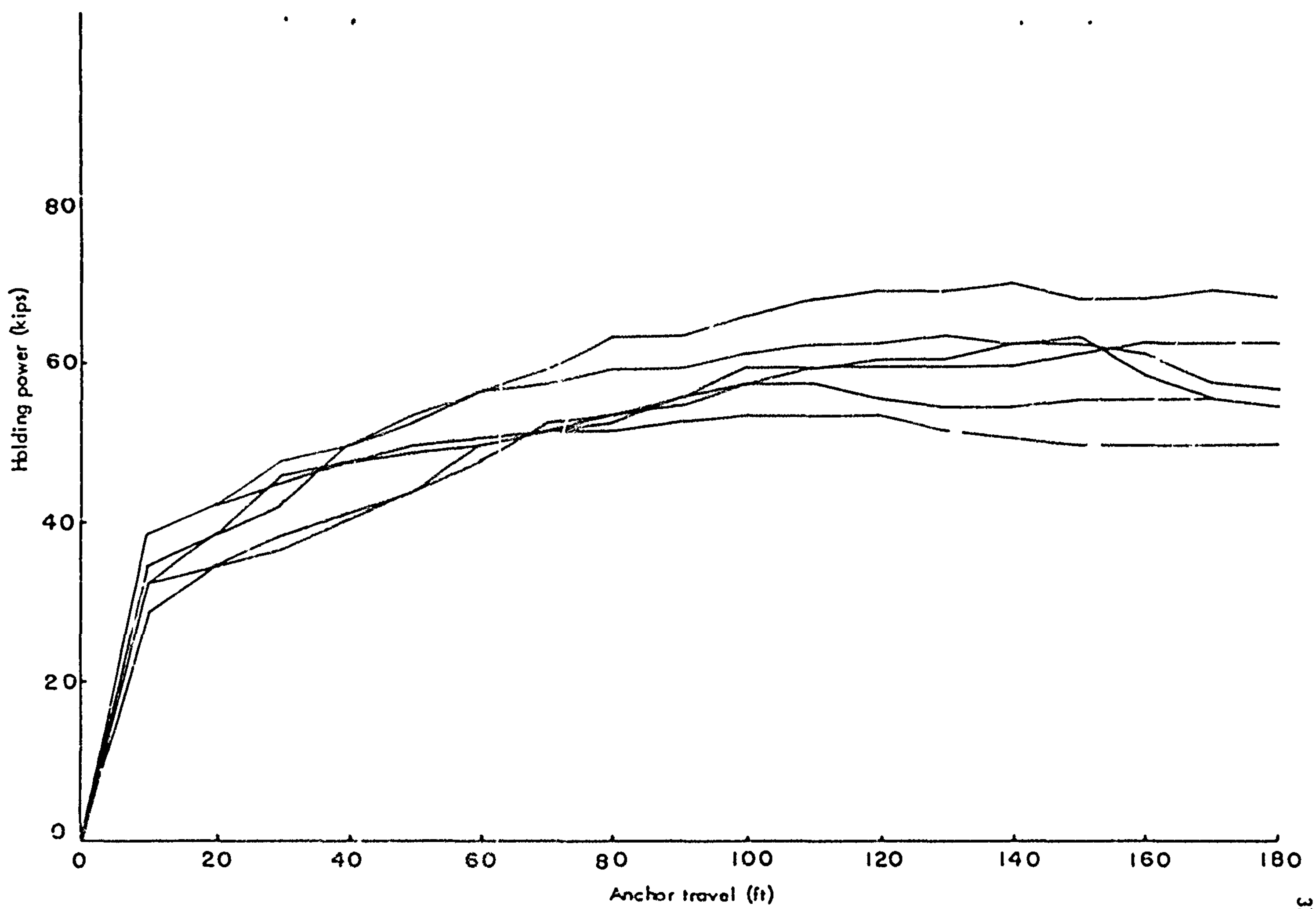


Figure 22. Graph of test pulls on 10,000-lb Navy steel anchor with fixed flukes

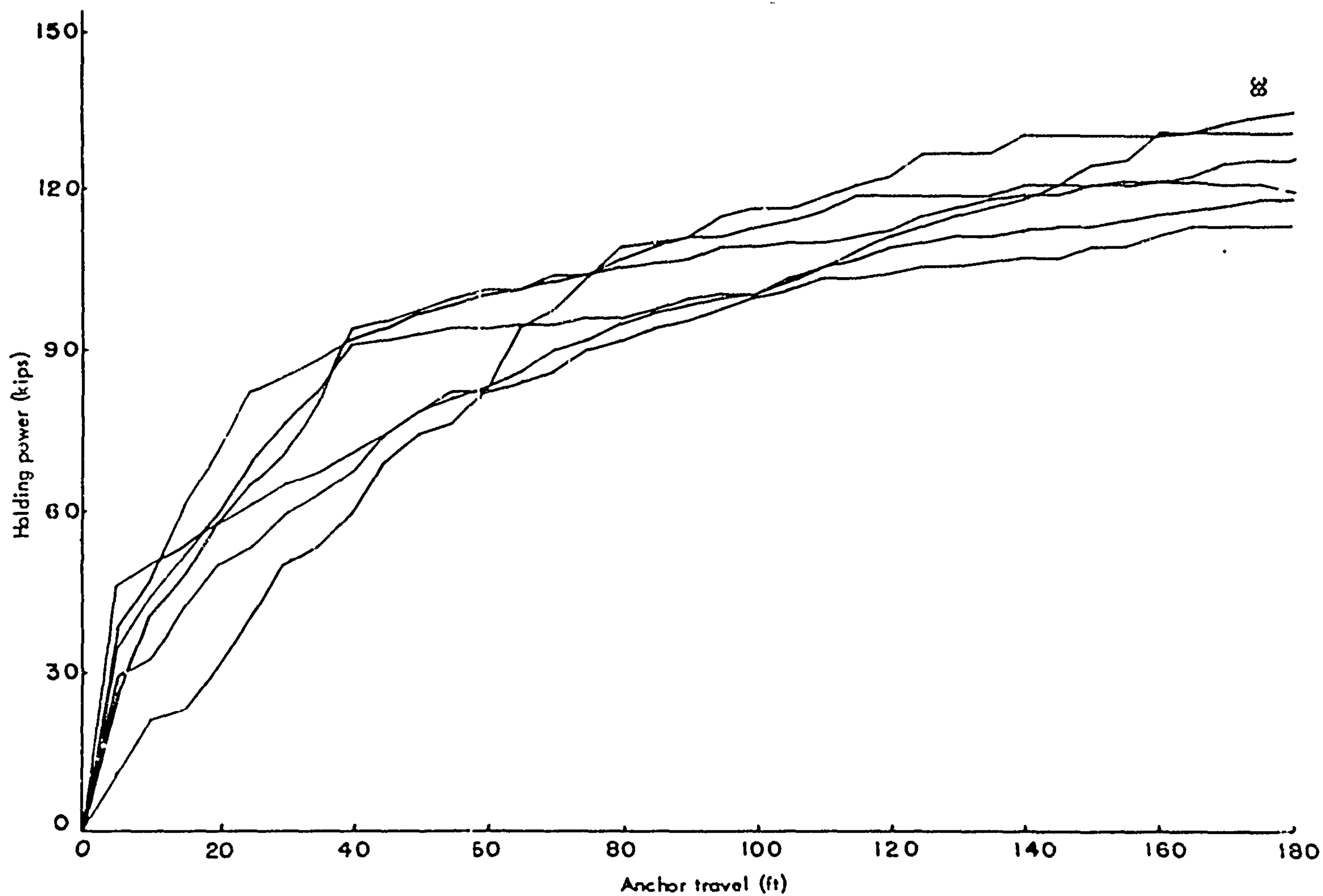


Figure 23. Graph of test pulls on 20,000-lb Navy steel anchor with fixed flukes

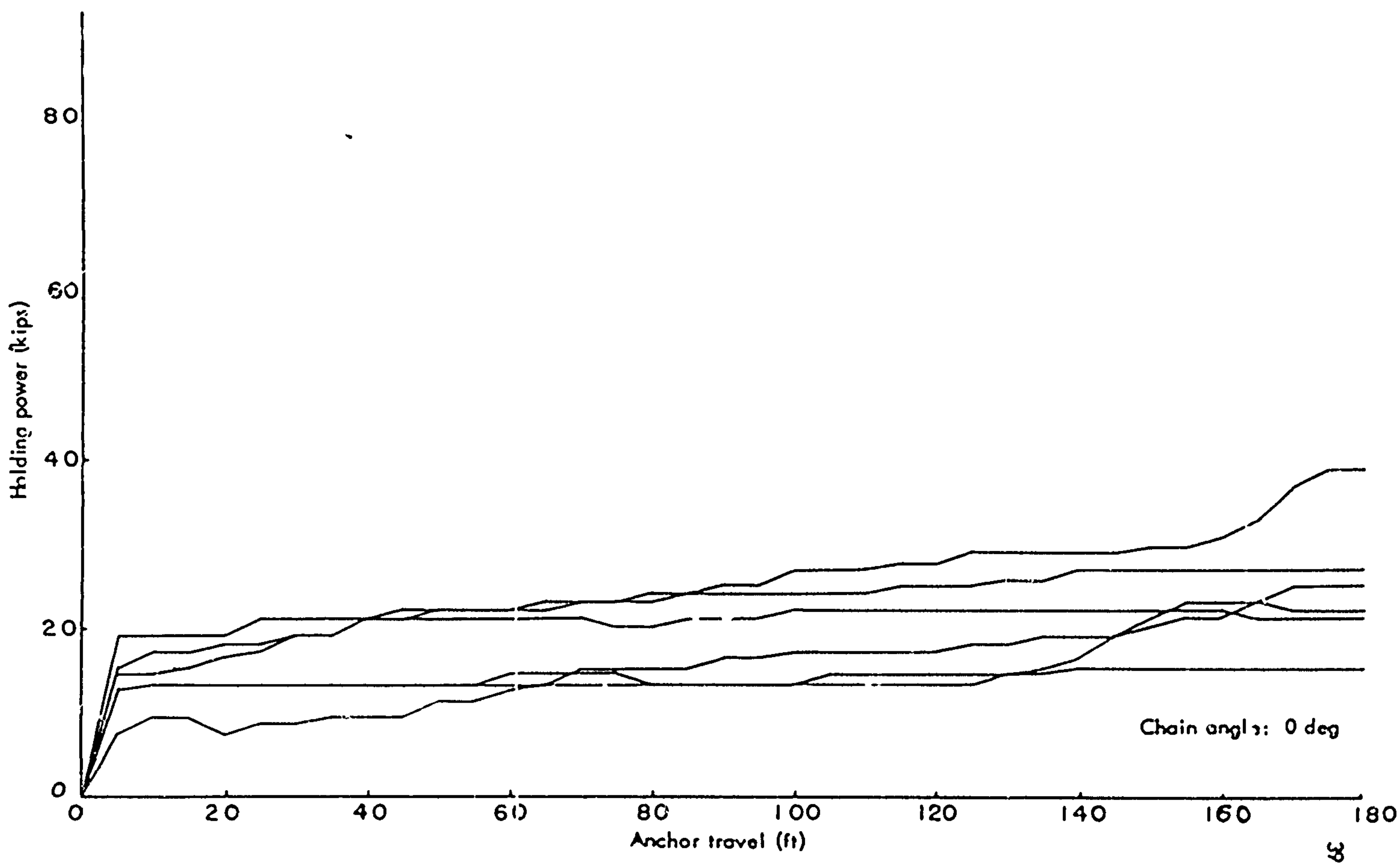


Figure 24. Graph of test pulls on 6000-lb Navy steel anchor with movable flukes

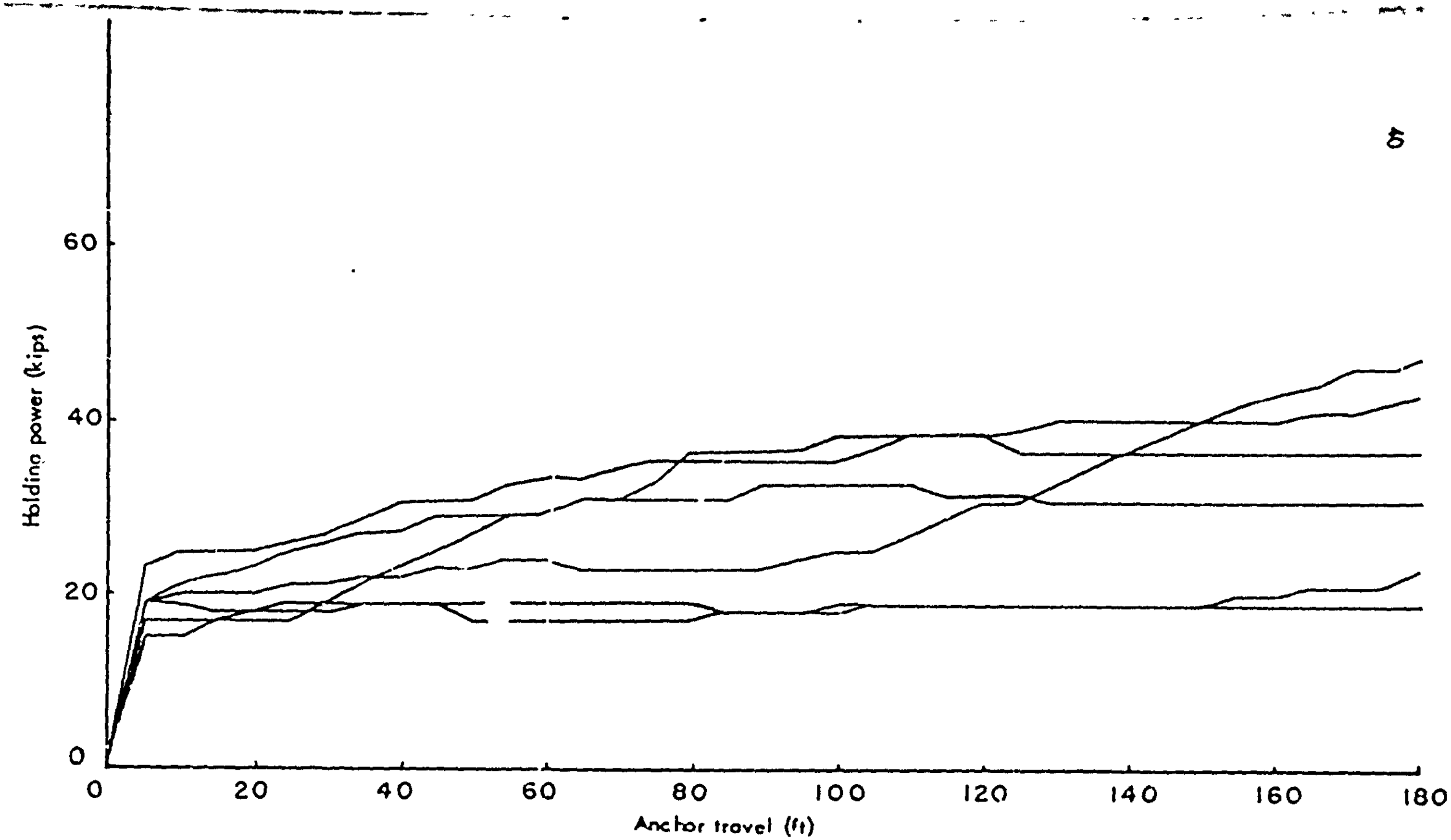


Figure 25. Graph of test pulls on 10,000-lb Navy steel anchor with movable flukes

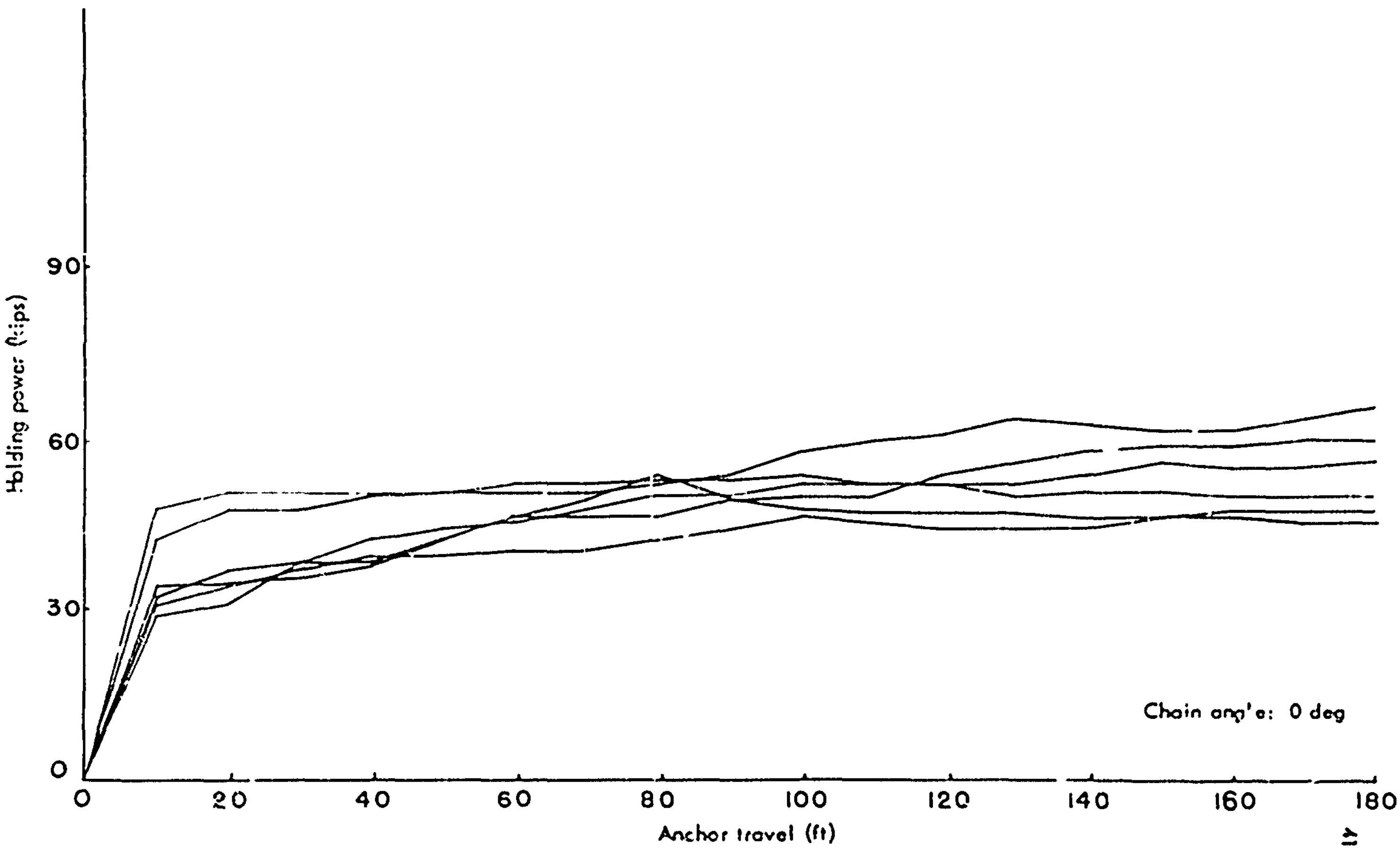


Figure 26. Graph of test pulls on 20,000-lb Navy steel anchor with movable flukes

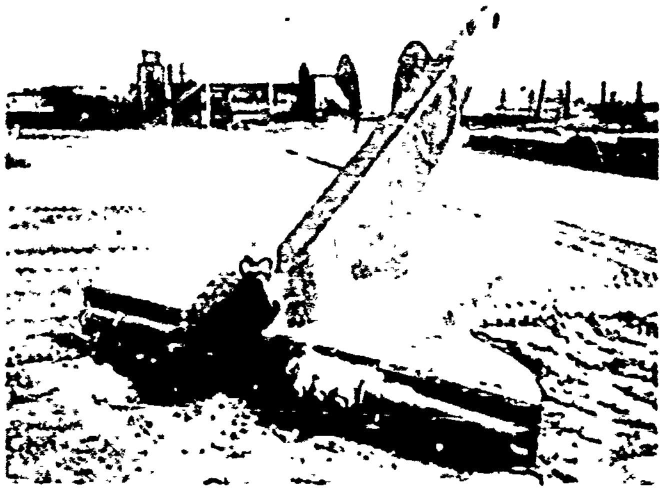


Figure 27. 7500-lb concrete-steel anchor

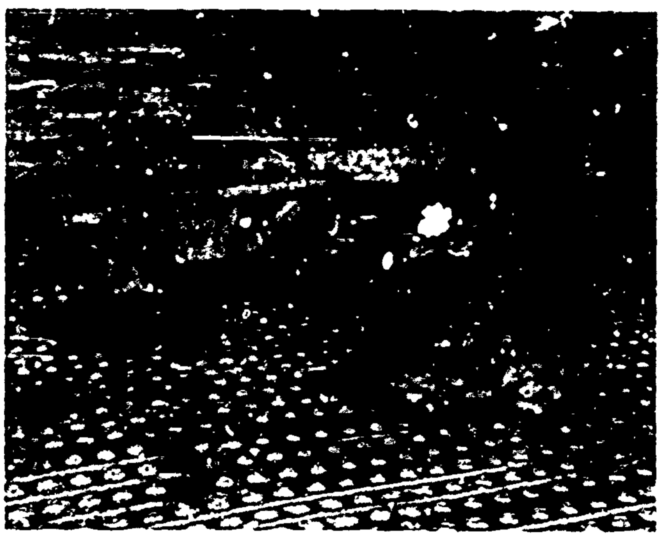


Figure 28. BuDocks 1430-lb straight-plate anchor

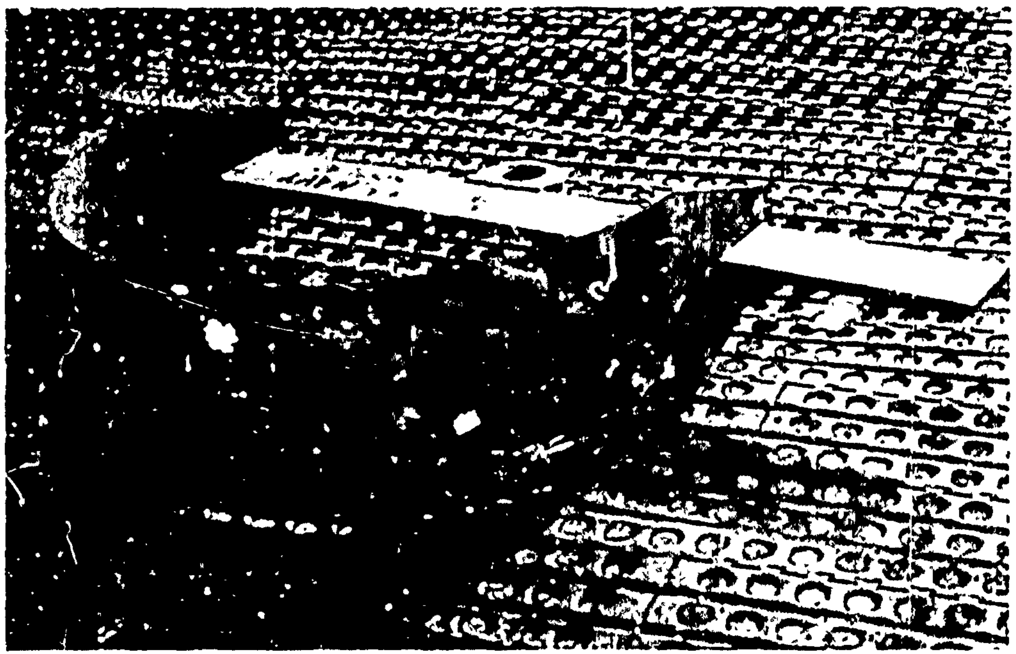


Figure 29. BuDocks 1430-lb curved-plate anchor

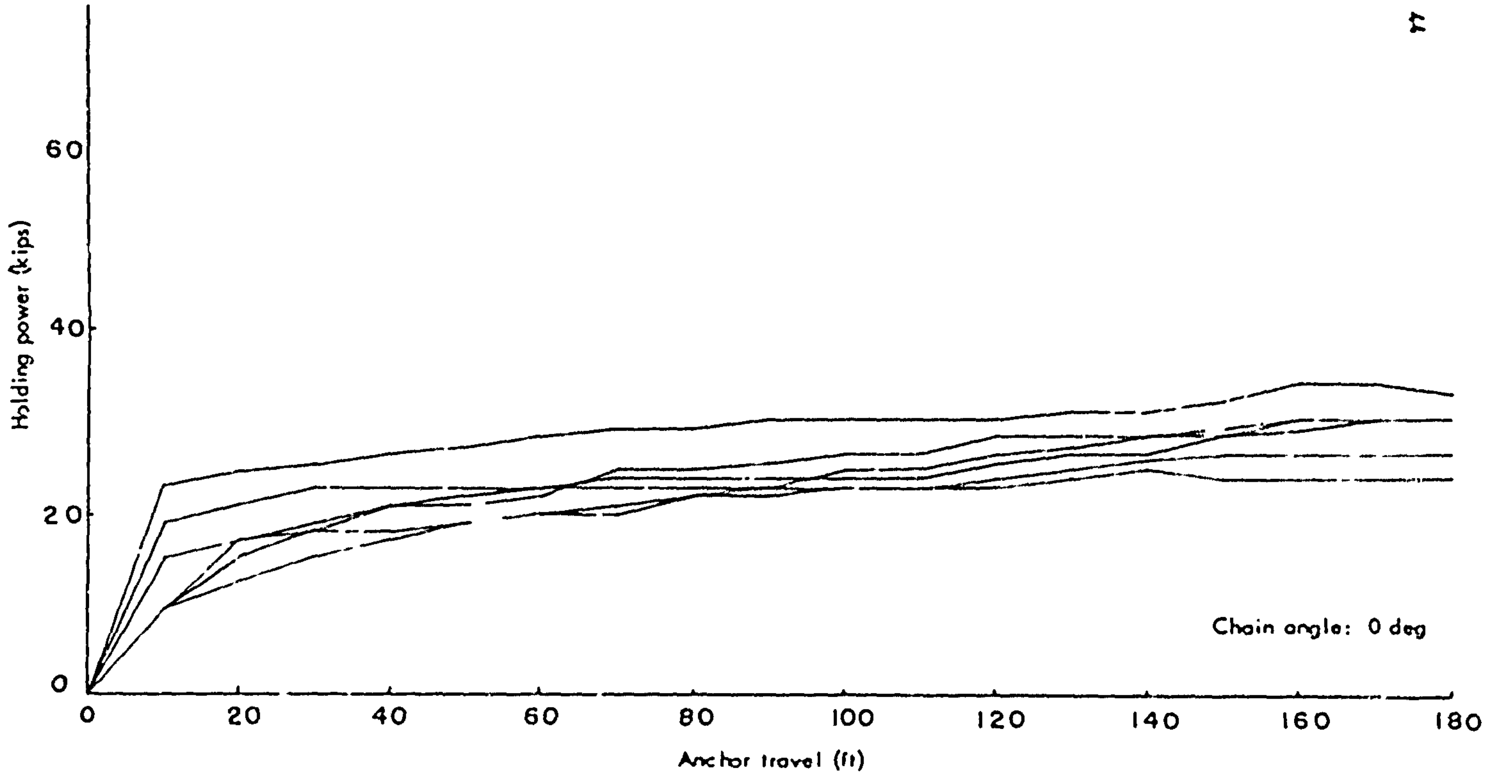


Figure 30. Graph of test pulls on 7500-lb concrete-steel anchor

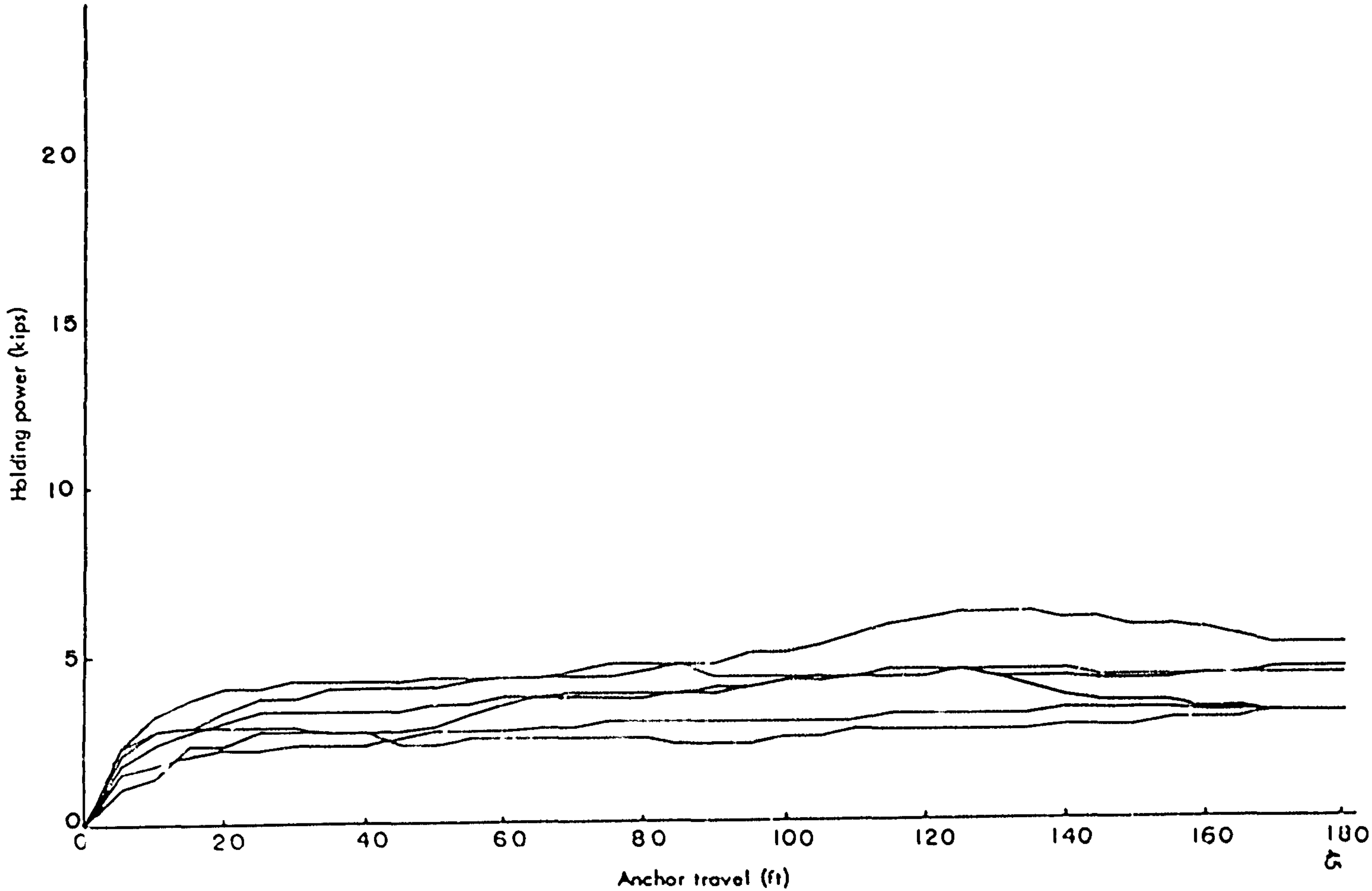


Figure 31. Graph of test pulls on 1430-lb straight-plate anchor

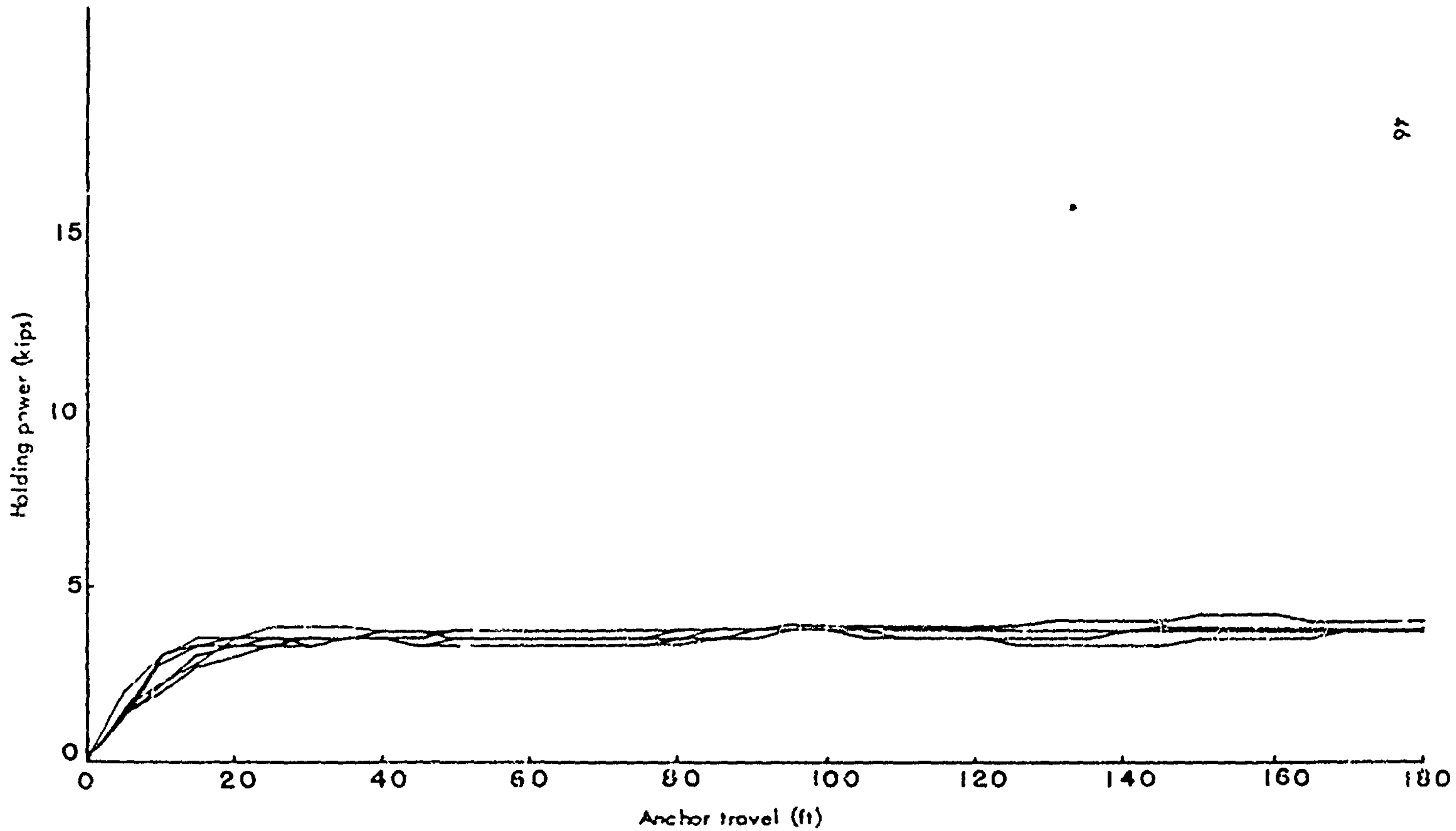


Figure 32. Graph of test pulls on 1430-lb curved-plate anchor

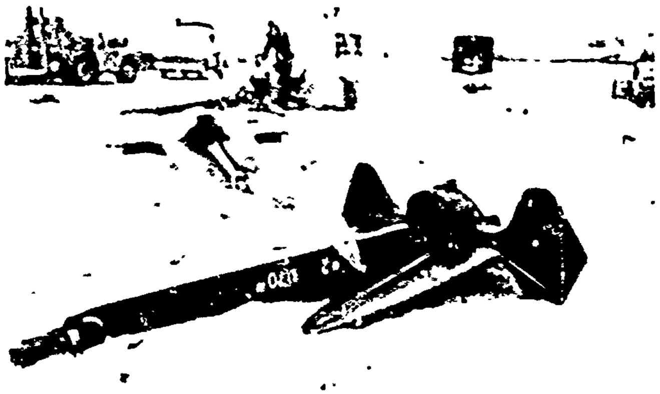


Figure 33. 3170-lb Baldt anchor

Figure 34. 3650-lb Baldt anchor

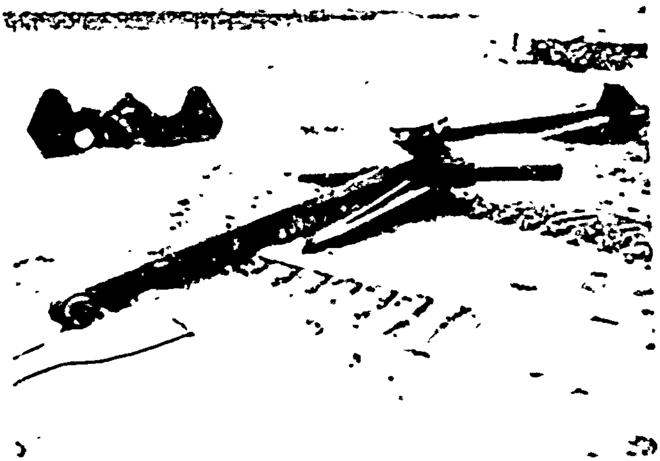


Figure 35. 3060-lb Croseck anchor

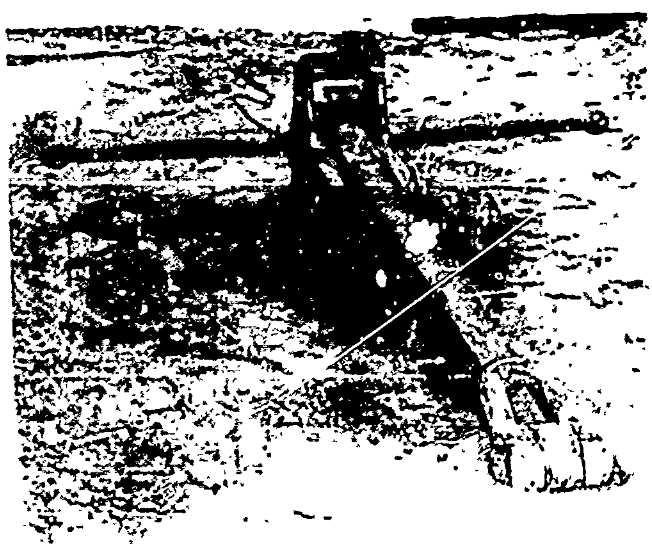


Figure 36. Typical Lightweight anchor

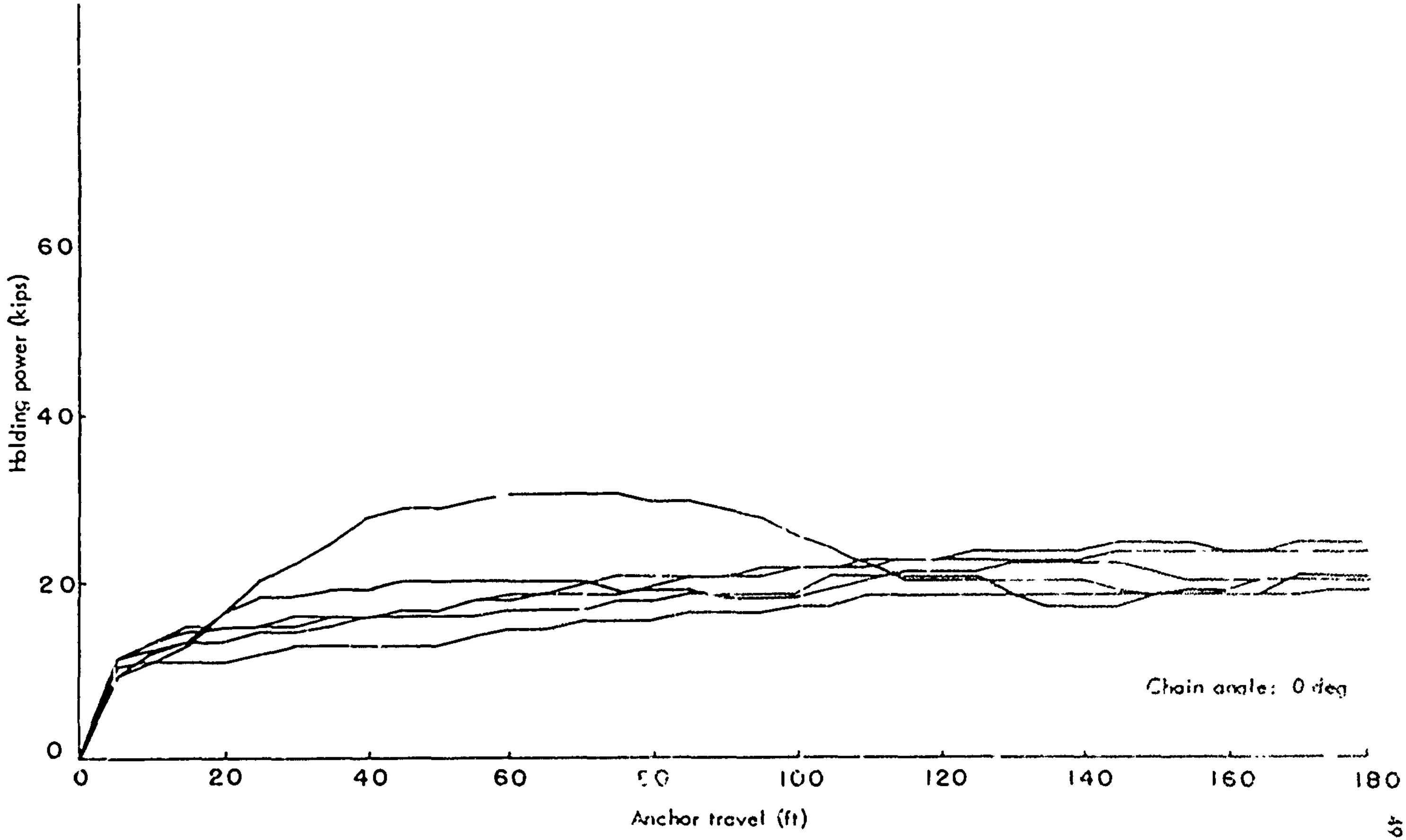


Figure 37. Graph of test pulls on 10,000-lb Lightweight anchor

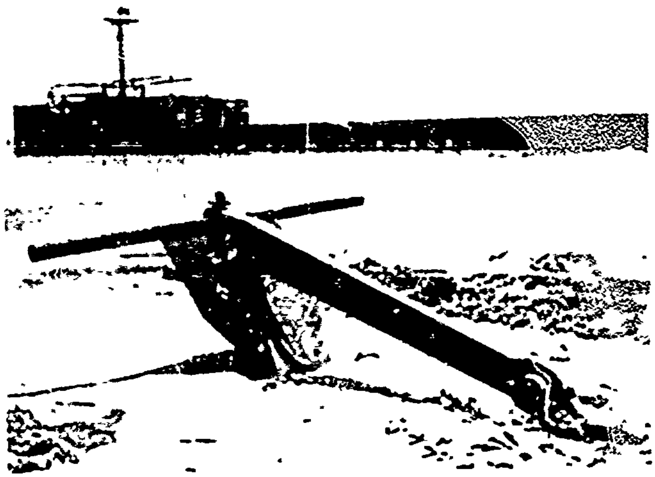


Figure 38. 2510-lb Danforth anchor

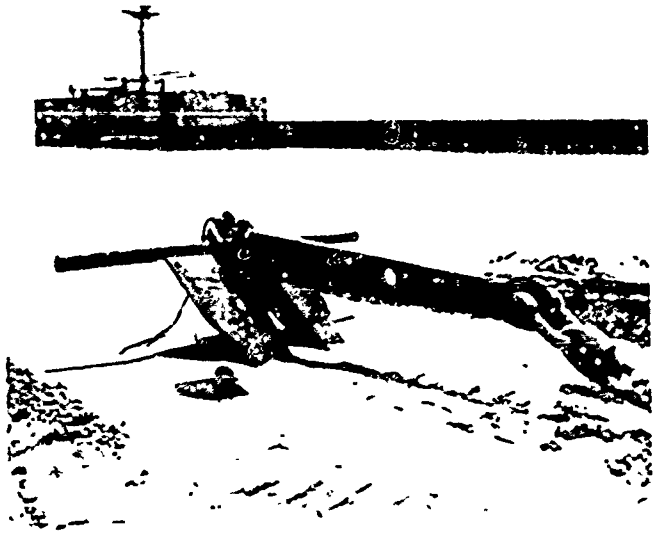


Figure 39. 2770-lb Danforth anchor

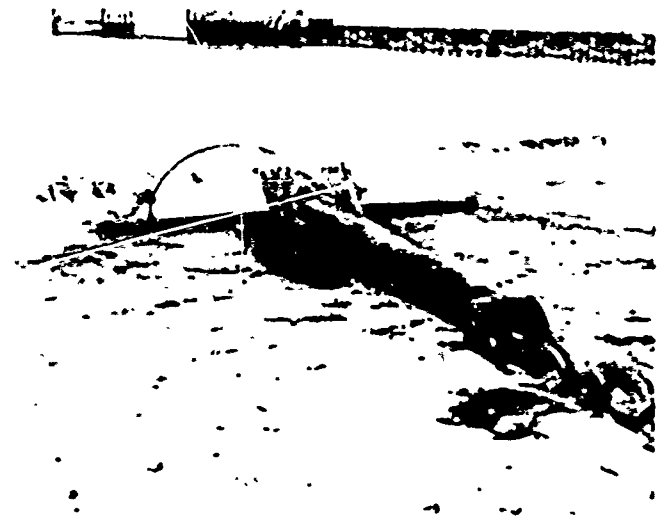


Figure 40. 10,000-lb Danforth anchor

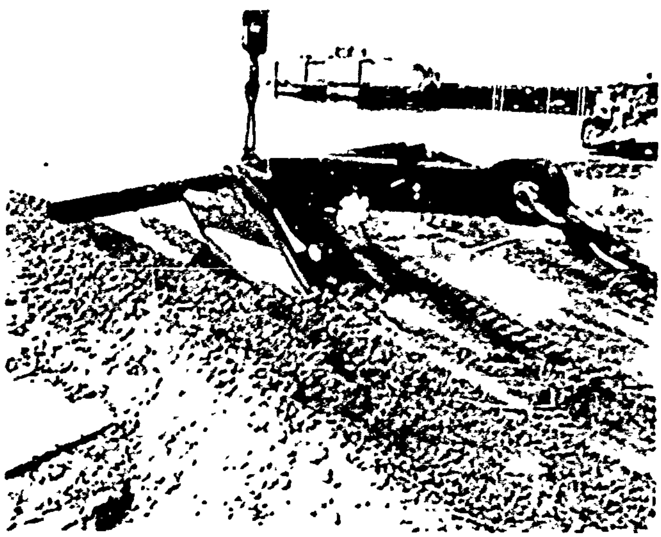


Figure 41. 12,000-lb Danforth anchor

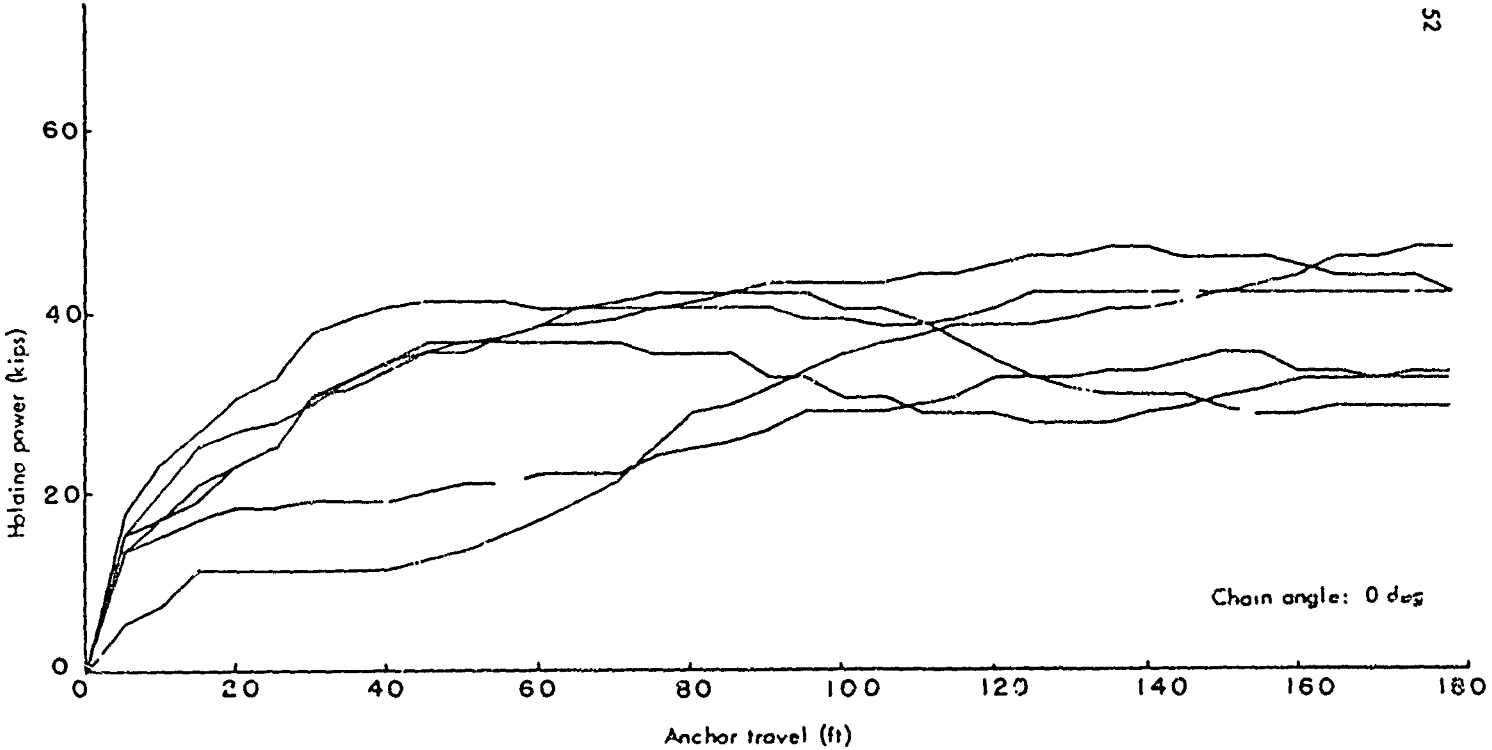


Figure 42. Graph of test pulls on 10,000-lb Danforth anchor

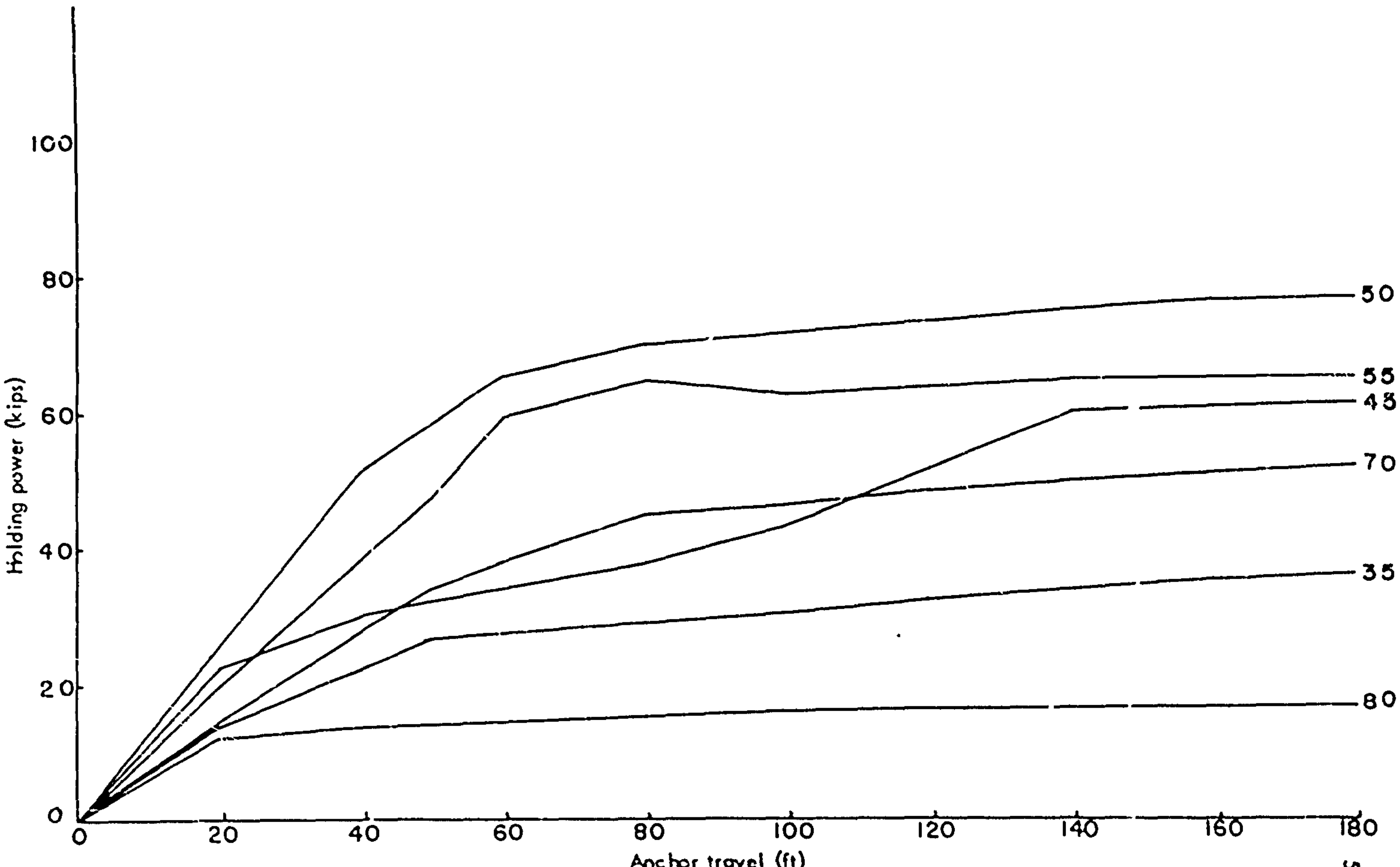


Figure 43. Graph of fluke angle tests (2770-lb Danforth anchor)

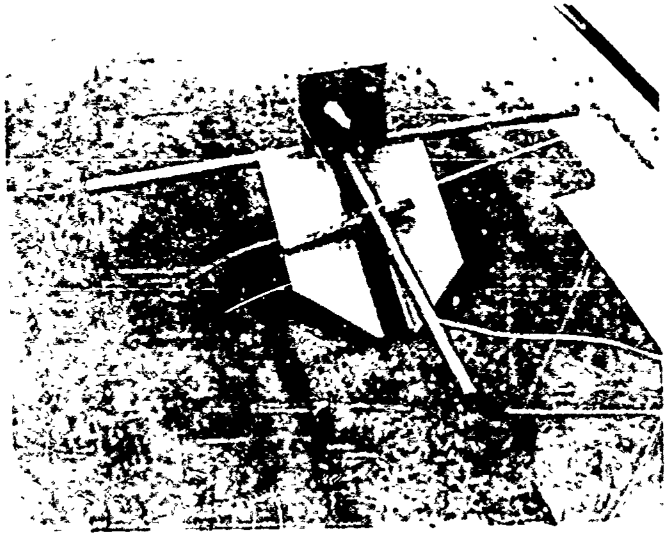


Figure 44. 1620-lb mooring anchor

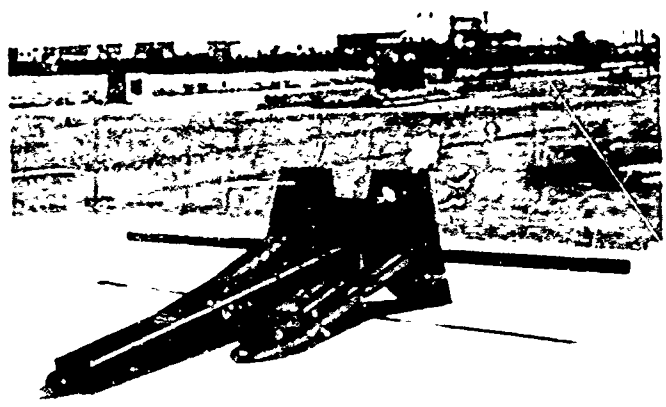


Figure 45. 2900-lb mooring anchor

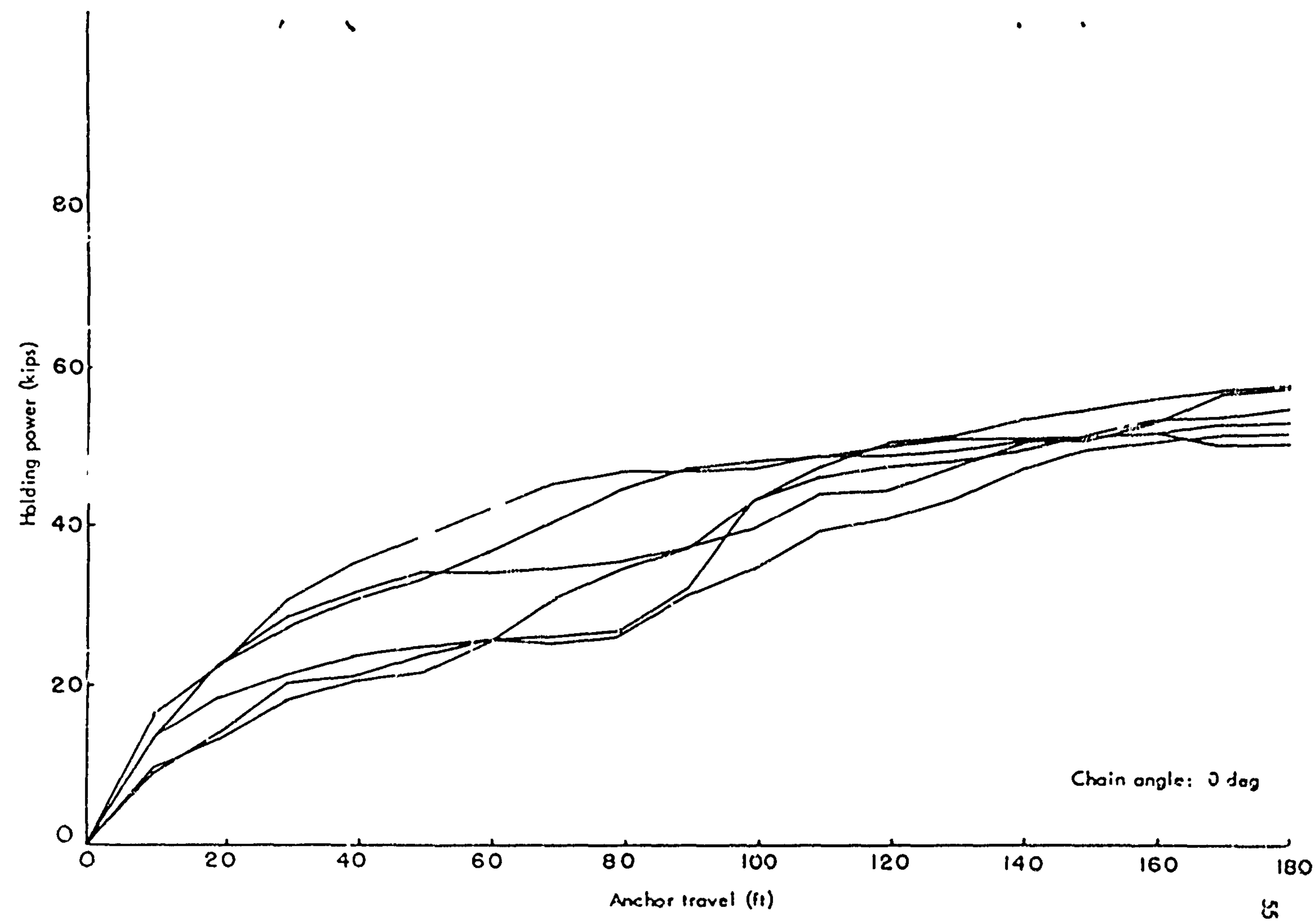


Figure 46. Graph of test pulls on 2900-lb mooring anchor

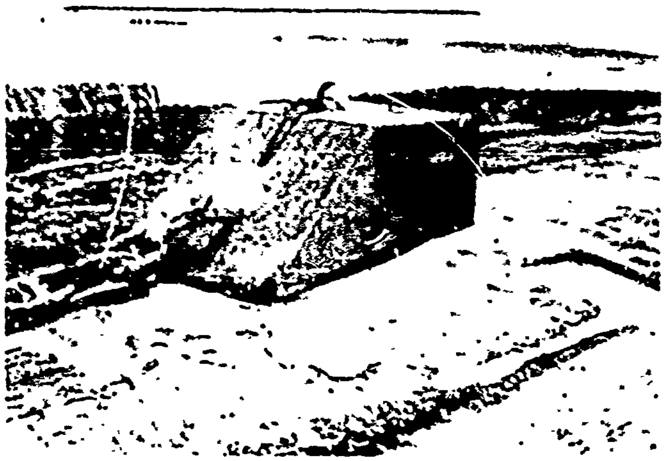


Figure 47. 10,500-lb concrete wedge anchor

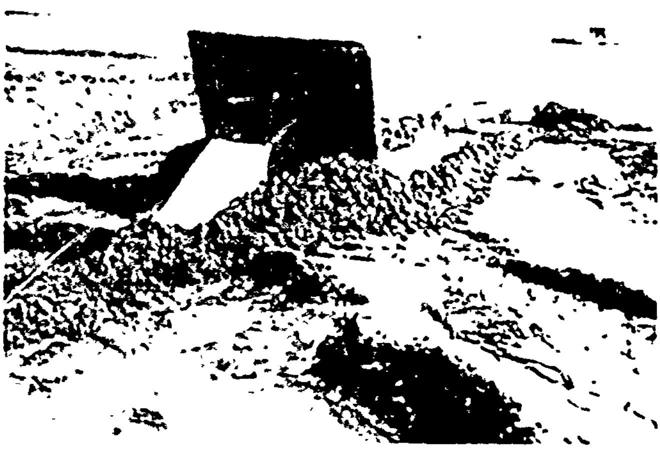


Figure 48. 10,500-lb concrete mushroom anchor

Figure 49. 2500-lb concrete mushroom anchors

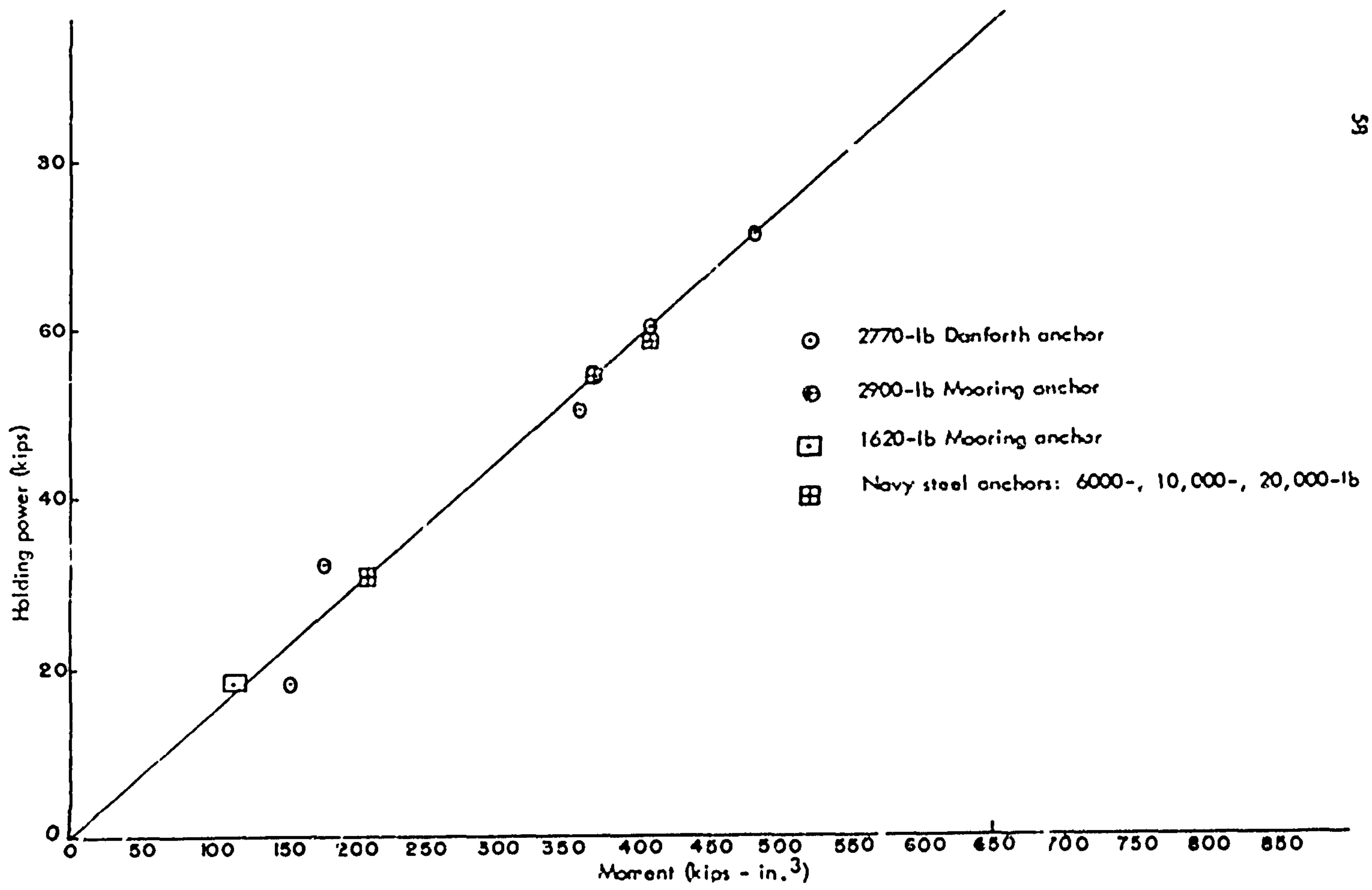


Figure 50. Holding power vs moment of fluke area

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Tests were conducted in a mud bottom to determine the holding power of the BuDocks-designed steel, concrete mushroom, and concrete wedge-shaped anchors, and to compare the behavior and holding power of these anchors with those of the present type stockless anchors, with and without stabilizers. Test results are given and recommendations are made.

1. Anchors
I. Towne, R.C.
II. Stalcup, J.V.
III. NY 420 010.5

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